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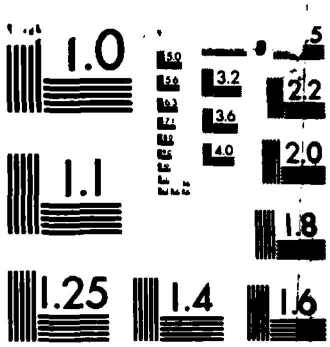

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ABSTRACT

Quality assurance functions at some major industrial manufacturers are confronted with test data on a massive scale and are not capable through manual methods of the in-depth analyses that are necessary for effective quality control. This report details the development of a quality control system for use at the Garrett Turbine Engine Company, Phoenix, Arizona, in analyzing the results of testing of vendor-supplied castings and forgings.

Traditional quality control chart theory and more elaborate statistical testing, such as analysis of variance, were integrated into computer programs to produce detailed quality control charts and summaries of data analysis and testing. These programs were integrated into a quality control system to allow management to make more timely and better founded decisions on accepting castings/forgings from vendors, modifying testing plans, and modification of material specifications, thereby reducing costs.

The testing results of two selected parts were used to verify operation of the programs. Three example situations were developed to demonstrate the system decision making; primarily comparisons of vendor and Garret testing of the same casting/forging and/or comparing different vendors. Further improvements were discussed and recommendations made.

Although the system was designed specifically for use by Garrett, it could be used by statistically experienced or inexperienced quality assurance personnel in other firms and/or manufacturing disciplines for effective data analysis.

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AN APPLICATION OF QUALITY CONTROL THEORY
TO VENDOR-SUPPLIED PARTS
AT AN AEROSPACE MANUFACTURING COMPANY

by

Daniel E. Gellenbeck

An Engineering Report Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

ARIZONA STATE UNIVERSITY

August 1985

AN APPLICATION OF QUALITY CONTROL THEORY

TO VENDOR-SUPPLIED PARTS

AT AN AEROSPACE MANUFACTURING COMPANY

by

Daniel E. Gellenbeck

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CHAPTER 1

INTRODUCTION

Background

Controlling the quality of procured hardware is a serious quality problem that companies must face (31:611). Because of increasing product specialization, most industrial and business concerns have found it necessary to purchase various parts and/or subassemblies from a number of suppliers (31:611). Logically, then, when a company does purchase from a number of vendors, some means of evaluating the individual vendor should be available. The basis for this evaluation should be the quality of product being supplied by the vendor. This report details an application of quality control theory to the evaluation of individual vendors at the AiResearch Manufacturing Company, Phoenix, Arizona.[1]

This report is divided into five chapters. The remainder of this chapter describes the problem to be

[1]AiResearch Manufacturing Company is now known as Garrett Turbine Engine Company. As the change occurred subsequent to research for this paper, references to AiResearch have been retained throughout. Any reference to AiResearch means Garrett Turbine Engine Company.

approached, a method for analysis, and goals that the project will attempt to fulfill. Chapter 2 discusses the basis for control charts, some approaches to situations that are peculiar to the problem, and previous examples of computerized quality control. Chapter 3 presents the computer program developed as a problem solution, while Chapter 4 presents two test cases utilized to verify the program. Recommendations for further study and a conclusion are included in Chapter 5.

Problem Statement

AiResearch Manufacturing Company, Phoenix, Arizona (hereafter referred to as AiResearch), receives, on a somewhat regular basis, shipments of various castings and forgings from a variety of manufacturers (vendors) for use in aviation and/or industrial gas turbine engines. Accompanying these shipments are the results of destructive testing of a sample of the castings or forgings as performed by the vendor. These results, in the form of Certifications of Compliance (CERTs) are routed to the Procurement Quality Engineering department for processing.

In order to check on vendor results and assure that the parts are acceptable, additional tests are conducted by the AiResearch testing lab ("in-house" testing). The frequency of this testing is included in the design specifications for each casting/forging. A sample specification is included in Appendix B. The results of these

tests, summarized in Chemical and Metallurgical Reports (CMRs), are then sent to the Procurement Quality Engineering department.

The results of vendor and in-house testing, summarized in, respectively, CERTs and CMRs, are compared to the specification minimum values and to the vendors' past performances on an intuitive basis. There presently exists, at AiResearch, no quick, efficient, economical method of comparing a particular vendor's current product with his past (historical) performance. A number of people in the Procurement Quality Engineering department who are familiar with a specific vendor's product, compare the present test results and make intuitive judgments on the reliability of the test results, and, hence, the reliability of the vendor's manufacturing processes.

Currently, the Quality Assurance and various Engineering departments at AiResearch are attempting to develop a system that will allow them to compare incoming vendor data with the past historical data of the particular vendor. By analyzing and comparing this data over time, changes in the process that would be detrimental to the quality of the casting/forging and, likewise, to the overall engine might be detected with greater accuracy than at present.

An AiResearch Office Memo, dated October 17, 1978 (Appendix A), summarizes the method to be used to develop the comparison system.

> After several meetings, the subject of which was the analysis of vendor generated and CMR data, it was the consensus of Materials Engineering, Quality Assurance, and Manufacturing Engineering personnel that the use of control charts would be the best method . . .

Additionally, this method of analysis is to be computerized in such a way so as to allow people with varying degrees of skill to update and compare data from many vendors. This will also allow Quality Assurance personnel at AiResearch to query the individual vendor to determine if the manufacturing process has been changed in a manner that would account for a variation in test data from past vendor performance or if another cause might account for a noted variation.

Goals

In order to solve the problem developed in the above problem statement, two main goals have been established that this project will attempt to fulfill:

1) A quality control statistical analysis of vendor and AiResearch data is to be automated in order to more efficiently track a vendor's performance and to allow storage of data to be both more flexible and less space-consuming.

2) After comparing the performance of a specific vendor's product over time, the need for the current testing level is to be evaluated with respect to predetermined

criteria for testing frequency, which will be determined as part of this project. If testing frequency can be reduced, the product specifications for this vendor can be changed to reflect the reduction.

If these goals can be accomplished, considerable cost savings may be realized in both the volume of testing and the amount of required handling and analyzing of test results.

Now that the problem has been defined and a method of analysis proposed, namely statistical quality control, it seems appropriate that some background of statistical quality control, particularly control chart theory, be discussed. Chapter 2 describes control chart theory in sufficient detail to justify the rationale of AiResearch personnel in specifying control charts as a solution to the problem.

CHAPTER 2

QUALITY CONTROL CHARTS

> . . . The object of control is to enable us to do what we want to do within economic limits.--W. A. Shewhart (27:356)

Quality Control

Before delving into the intricacies of quality control charts, an understanding of what is meant by quality and control of quality is necessary.

Quality may be defined simply as the level of *performance* of a product in fulfilling the expectations of the customer (17:27). In order to effectively measure this "level of performance," many of the engineering and manufacturing characteristics of a product may be considered. Product quality emphasis has in fact become a leading force in economic growth (10:22).

Quality control had its beginnings in 1924 when Dr. W. A. Shewhart of Bell Telephone Laboratories first applied a statistical quality control chart to manufacturing operations. During and following World War II and the Korean War, the Department of Defense widely used quality-control techniques in procurement of goods and services. This influenced the quality-control practices used in industry.

Control of quality involves two major aspects. The first is measuring the product characteristics that are significant in indicating product performance and analyzing this data to determine negative trends that may be affecting performance. The second aspect involves providing corrective action to offset the negative trends found above. Corrective action may be applied to any of the three general stages of the production process (Figure 2-1): incoming materials, components production or final assembly (35:4, 17:29).

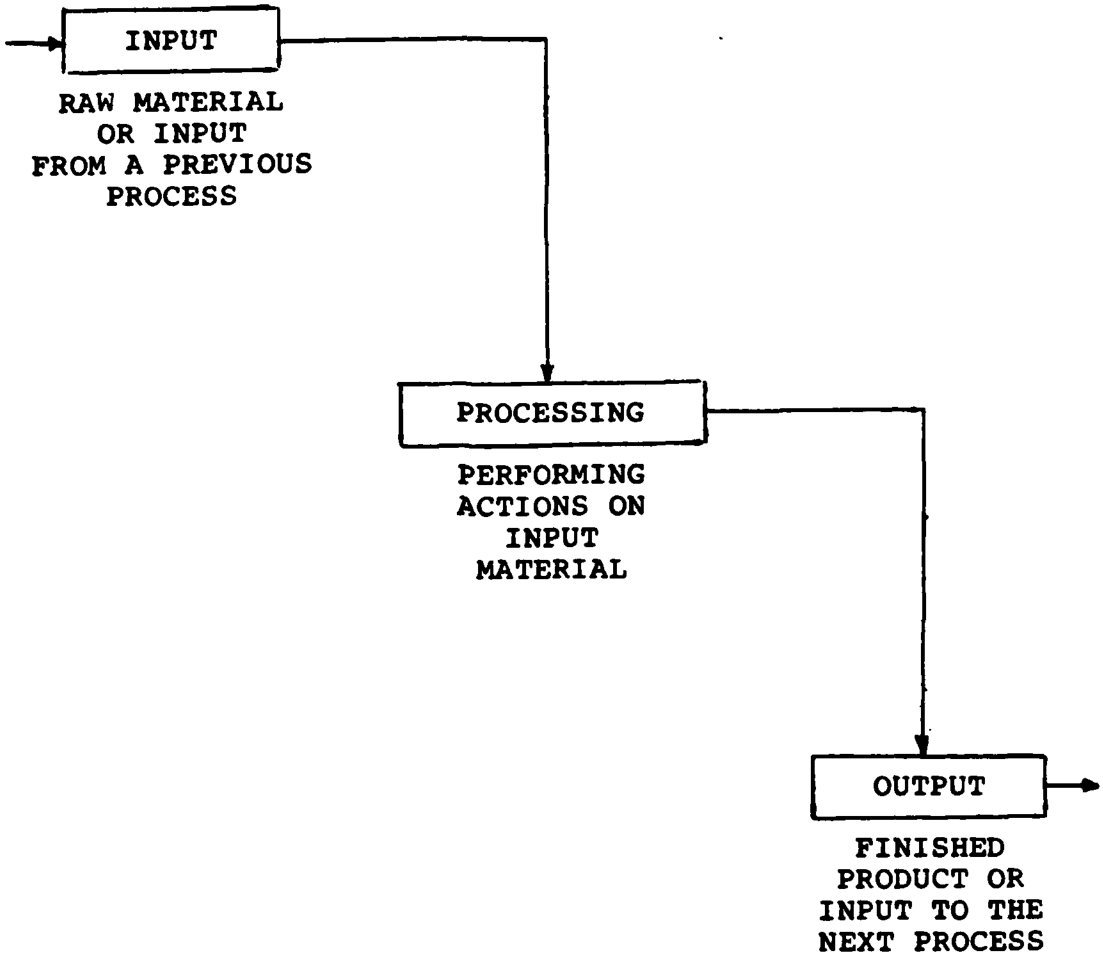
Quality control, then, is accomplished by first asking the process whether its average or central tendency has changed and/or whether its spread (dispersion) has changed (25:35). If an out-of-tolerance condition is detected (where tolerance is the specified spread in a measurement), then a correction is applied to an appropriate area of the process and its effect in bringing the condition back into tolerance is measured.

A moment's reflection will indicate that quality control is only as good as the data it generates and is useful only to the extent that management can understand and use the information provided as a basis for decisions. Problems arise, however, in providing the data in terms that management can understand and/or use effectively.

Fiegenbaum (11:67) and Kirkpatrick (15:11) both view quality control as a feedback function where measuring,

FIGURE 2-1

Stages of a Process



analyzing, and planning are a continuous cycle. Figure 2-2 illustrates and summarizes quality control as a feedback function. Initiation has been added to more fully represent how a quality control system actually operates. While most quality control efforts begin measuring a certain characteristic of a product, it should be remembered that any of the four areas may serve as the initial action.

Before discussing sampling inspection and methods of accomplishing it, the involvement of statistics in quality control should be addressed. According to Fiegenbaum (11:39-40), there are four basic statistical tools that have had a profound effect on quality control. These tools are:

1. The frequency distribution of particular quality characteristics, which provides a graphic portrayal of the quality of a given product.[2] It can provide, at a glance, information about the average quality level, the distribution (spread) of the quality, and how the quality compares with established standards.

2. The control chart of quality characteristics, which provides a chronological history of a product's performance. It can indicate, graphically, negative performance trends that would detrimentally affect the process if not corrected. In other words, it can be used to maintain control of a process.

3. Sampling Tables, which yield the probable quality of a given number of product units (a lot) when the proper number of samples are selected from the lot. Quality of material

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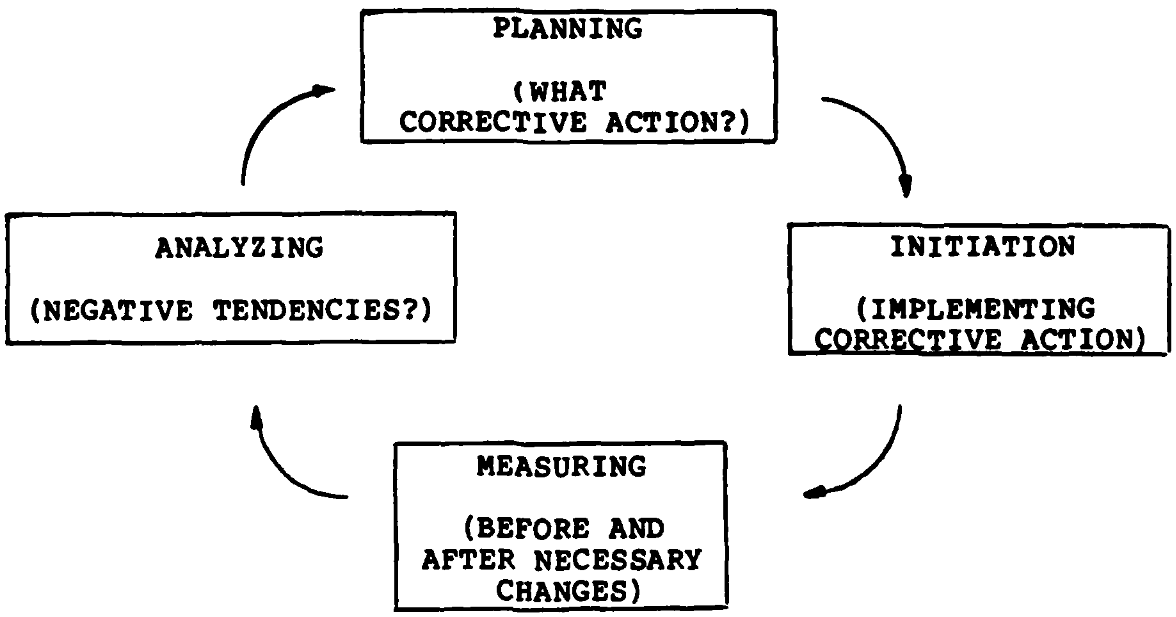
[2]Product, when used in this paper, refers to any process or device that is the result of a manufacturing procedure.

FIGURE 2-2:

Quality Control as a Feedback Function



either received or produced can be assured through use of these tables.

4. Specialized methods, such as analysis of variance and other techniques, have been adopted from the general body of statistics for use. These techniques can be used to investigate problems in a process or for specialized analyses of designs.

Statistics, along with other tools such as simulation and information systems, form a powerful means of solving quality control problems that exist in industry.

Standards

Standards are based on the scale of measurements used (such as inches, millimeters, pounds, etc.) and on the limits of acceptable products (25:112). For example, a particular shaft in a mechanical assembly can have a diameter of 0.245 in. to 0.255 in. without having a detrimental effect on the operation of the assembly. The limits, 0.245 in. and 0.255 in. in the example, are frequently referred to as specifications. They are (or should be) based on engineering considerations that must be met in order that the product will perform as intended (29:163).

In other words, standards and specifications define limits, stating how far (.005 in. in the example) from perfect the product can be before it fails to be

acceptable. They are used to protect against all objectionable variations and are set up for any or all of the following purposes (25:112):

a) Ensure interchangeability of parts.
b) Determine the difference between good and bad product based on the ability to function.
c) Determine the difference between good and bad product based on the expected effects of aging and/or usage (reliability).
d) Determine the difference between good and bad product based on the aesthetic appearance.

Specifications and standards also serve to assure continuity and uniformity in the evaluations of many inspectors and to allow the management group to make the necessary major quality decisions. Setting such specifications compels management to investigate the required design needs and capabilities and to make a decision, from a financial and economic standpoint, between the high cost of quality and customer satisfaction (27:113-4).

In other words, if management sets specifications/-standards too rigidly (tightly), the product will probably perform properly but may cost an excessive amount to produce. On the other hand, if the set specifications are not rigid enough (loose) the production costs will probably not be excessive, but the product may not perform adequately. Such important decisions, according to Samson, Hart, and Rubin (25:113), should not be based on the recommendation of an engineer who is asking twice his needs because he knows he'll get half of what he asks; nor should

they be based on the request of a production manager who is asking for specs[3] twice as loose because he knows the engineering department will tighten them anyway. To achieve the desired optimum profit, management must be certain to set precise standards that are neither too tight nor too loose to ensure the product will perform adequately and can be produced economically.

Inspection

For some industries, it is necessary to inspect each item produced and/or received from a vendor to identify and reject all defective items. Such 100 percent inspection accompanied by rejection of all defective items is termed "screening" (30:10). Inspection of this type is the only way to guarantee the rejection of all defective items and only defective items. Effective screening inspection, however, requires automatic machinery to eliminate the human error of misidentifying good items as defective or an inspector's work load must not be so excessive as to impair accuracy.[4] Suitable machinery is costly if it is available, and even utilizing a human inspection system makes screening quite expensive in personnel and time.

---

[3]Specs is short for specifications.

[4]A statistical study conducted at Franford Arsenal, Philadelphia, indicates very clearly that the percentage of items classified erroneously increases sharply with the volume of inspection (30:10).

Additionally, screening rarely is able to eliminate all defective items. Of course, if the quality test for an item is destructive (as it is in the case of metallic castings and forgings), screening cannot be used.

Screening contributes very little to the improvement of the quality of product delivered in the future; there is very little, if any, feedback of information to the supplier (vendor) since only rejected items are returned. One can, thus, tell very little about the manufacturing process from a screening inspection.

Inspection, in respect to control of product quality, may basically be defined as comparing the quality characteristics of a product to the standards/specifications applying to the selected quality characteristics. This is done to fulfill one or both of the objectives of inspection: 1) whether material produced should be accepted or rejected; 2) whether corrective action should be taken on the production process (25:55). Inspection cannot improve the quality of a process of and by itself. Rather, the corrective action indicated by the sampling information improves quality which can reduce costs.

To obtain the necessary information for quality control decisions, an acceptance sampling plan is usually employed that utilizes an inspection by attributes (pass/fail plan) or an inspection by variables (measurement plan).

<u>Acceptance Sampling</u>

Incoming materials should conform to the specifications and tolerances submitted to the supplier as part of the purchase order. To ensure this conformance, acceptance sampling of each shipment (lot) of material is necessary. There are two means of sampling, according to Lester, Enrick, and Motley (17:141):

1. Sampling prior to receipt of the purchased materials; also known as advanced sampling.
2. Sampling upon receipt; also termed on-arrival sampling or sampling for receiving inspection.

Advance sampling involves the vendor sending samples to the consumer (or the manufacturer in the case of AiResearch) or the vendor conducting tests in accordance with the manufacture-approved procedures prior to shipping the lot of material (both apply to this report). The advantage of re-routing or refusing a lot prior to delivery to the consumer is significantly outweighed by a number of possible events.

1. Contamination or other damage occurs during transit.

2. An overzealous person(s) at the vendor ships pretested samples that are not representative of the actual lot quality.

3. Unethical practices such as "salting" (defective items are added to material of high quality level, while keeping the percentage of defectives within the limits

specified by the consumer) are not detected.

On-arrival sampling allows random selection of units under the user's (consumer's) quality control system, but delays using the items immediately while samples are being tested and until acceptance decisions are made. Another drawback is that the consumer must have the necessary test equipment or must contract out that function.

Whenever possible, samples from actual regular production should be checked for their conformance to specifications. The data obtained from these samples can be used to develop a history of the vendor's (supplier's) performance, according to Lester, Enrick, and Motley (17:146). This is quite important in the case of a new supplier, since it gives the consumer an appraisal of the supplier's ability to meet quality, cost and delivery requirements. Vendor quality histories and ratings can be quite effective in the long-term monitoring of vendor performance and can be used to keep acquisition personnel (i.e., purchasing) current on vendor quality.

In some cases, it may be beneficial to certify a vendor as supplying consistently high quality product, thus protecting the purchaser from unacceptable product sources and reducing the need for inspection. Swaton and Weaver (31:611-616) advocate a program for acquisition of castings and forgings such as those acquired by AiResearch.

Acceptance sampling plans are characterized as lot-by-lot sampling inspections. In this type of inspection, the product is divided into appropriate inspection lots (for example, the number of items poured from one "melt" of metal, as in this study; the number of items produced in a day's production, etc.) and a sample or samples are drawn from this lot and tested. The inspection lot is then accepted/rejected (sentenced) on the test performance of the selected item.

There are, of course, advantages and disadvantages to acceptance sampling. There is a possibility that good items are rejected and, since not all items are inspected, bad items accepted. In other words, because the test items will follow the laws of chance, the result of their testing occasionally will not indicate the true quality of the lot. However, if the acceptance sampling plan is well-designed, in a statistical sense, the chance of this happening is greatly reduced. When these risks are balanced against the great cost savings, sampling inspection will generally be preferred to screening or 100% inspection (30:11). In the case of products that can only be tested destructively, acceptance sampling is necessary and will provide protection against accepting more than a very small number of low quality lots. That acceptance sampling is the only economical means of evaluating products requiring destructive

testing is the opinion of authorities in the field of quality control.[5]

This author found it interesting that AiResearch had attempted to perform a screening operation on all vendor-supplied castings and forgings by including a prolongation ring in the specs for all castings and forgings. This ring, cast or forged into the incoming products, was then machined off the item and portions of it subjected to destructive testing. While theoretically sound, this screening plan did not operate effectively because the properties of the prolongation ring could not be correlated with those of the casting/forging from which the ring was cut. Management then decided it needed an economical acceptance sampling plan to ensure that quality castings/forgings were being placed in their engines.

Inspection by Attributes

Inspection by attributes involves subjecting the selected test item to a specified level of the chosen testing characteristic. As a rather simplified example, let's say management wishes to test vendor-supplied steel rods on their ability to hold two-hundred pounds of weight. The acceptance sampling plan might be to divide the steel rods

[5]See, for instance, Weatherill (35:3), The Statistical Research Group of Columbia University (30:11), and Duncan (9:156), among others.

into lots of one-hundred and randomly select 5 for testing (5%).[6] The inspection by attributes for this plan would be to secure one end of the test rod and hang two hundred pounds of weight from it (Figure 2-3).

If three or more of the five rods can successfully hold the weight without breaking (i.e., pass the test), we accept that lot of one hundred. If only one or two of five pass the test, we reject the lot. If the lot is rejected, it is sent back to the vendor.

This type of inspection provides more information to the vendor than screening each rod does (he has the whole rejected lot instead of only the rejected ones), but the results do not indicate what can be done in the manufacturing process to improve the rods. While testing costs are substantially reduced (only 5% of all rods submitted are tested, versus 100% in a screening), there is still no feedback information available to correct the deficiencies in the manufacturing process.

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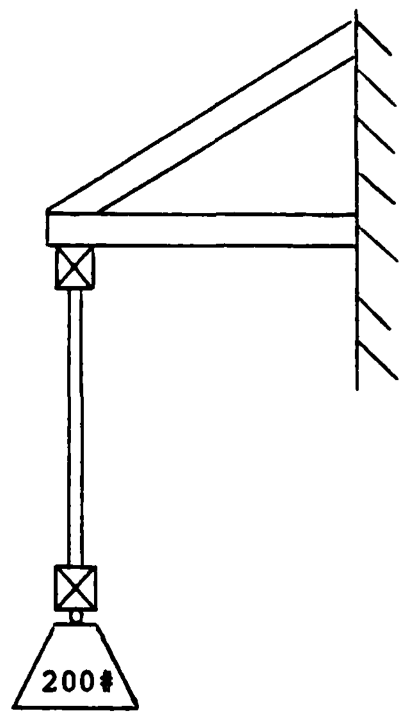
[6] The number of test items selected and the size of the inspection lot has a great impact on the economy of the test. According to the Statistical Research Group of Columbia University (30:42), the operating characteristic (OC) curve of a sampling plan (to be discussed later in this report) depends on the number of items selected per inspection lot; the higher the number the better the protection plan gives against rejecting high-quality and accepting low-quality lots. However, the total cost of inspection depends on the percentage of submitted products that are inspected since both a large number of items is desired in each sample (for good protection) and a small percentage of items is desired (for low cost), it follows that large inspection lots are required. The lot size chosen for this example was done so arbitrarily and may be assumed to be the most economical.

FIGURE 2-3:

Testing Apparatus
For Test of Steel Rods



<u>Inspection by Variables</u>[7]

If a characteristic (variable) can be measured upon which the quality (or acceptance) of an item depends, it may be possible to operate an inspection by variables (35:32-3). The advantages of this type of inspection system over an inspection by attributes include the following, as discussed by Fetter (12:19), Samson *et al.* (25:73) and Duncan (9:156), among others:

a) Fewer items must be inspected to give the same degree of assurance regarding acceptance/rejection. This method, hence, is less costly than 100% inspection.

b) It provides quick feedback of information for diagnosis and correction of process quality control deficiencies.

c) Since the decision to accept or reject a "lot" of material (the batch or group of product of size "n" that is submitted for testing [30:4][8]) is based on a measurement of a chosen quantity rather than on a discrete (pass/fail) test, the proper weight is given to each item being tested, in order to make a decision on (sentence) the lot. Rather

---

[7]This type of inspection plan is also referred to as acceptance sampling by measurements and variables sampling, among others, in the literature (12:8, :102, 3:64, *et al.*).

[8]In the case of castings/forgings the lot size is that number of items made from one "pour" of molten material.

than base the decision on a set number of test items passing/failing a minimum (or maximum) level as in attribute sampling, variables sampling bases the sentence on the probable behavior of the remainder of the lot as determined by measurement of the chosen property of the test items (castings/forgings).

There are disadvantages, too, such as the higher cost of inspection (especially instrumentation), the greater time usually required, and the more complex computations involved. These are outweighed, however, when the inspection is destructive as is the case in this situation.

This type of inspection is accomplished by measuring quality along a scale (17:120). Such measurements might be in inches, centimeters, degrees of temperature, kilograms per square inch of yield point, etc. The procedure would be to take a sample of size "n" of a particular property, and compute a statistic of the sample, for instance the mean (average), and then compare it to an accepted standard usually expressed in terms of limits. If the mean falls within the limits, that particular lot of material from which the sample of size "n" was drawn is accepted. If not, it is rejected.

One of the basic assumptions of a variables inspection plan is that the distribution of measurements of the chosen characteristic is approximately normal. Burr (5:563-568), Owen (21:454), and Rossow (24:135) conducted research that

indicates variables sampling plans (in particular $\bar{X}$ and R control charts) remain useful unless the normality assumption is severely violated. Berthoex, Hunter and Pallesen go on to add:

> It is fortunate, however, that even when the standard assumptions are seriously violated and the simple (quality control) charts can no longer be used quantitatively, they may nevertheless still provide useful qualitative information(4:139)

Operating Characteristic (OC) Curve

According to Duncan (9:147), the power of a sampling plan to discriminate between good and bad product is revealed by its operating characteristic, or OC, curve as it is termed. This curve shows how the probability of accepting a lot varies with the quality of the material offered. Another way of saying this, stated by Kirkpatrick (15:184) is that an OC curve describes the probability of accepting H_o (the null hypothesis) for various H_1-values (alternate hypothesis) for a fixed risk factor α.[8]

An assertion about H_o carries the risk α of making a wrong decision; the null hypothesis being incorrectly rejected when nothing has been introduced into the process to change the value of the statistic (for example, μ_o).

---

[8] α = probability of rejecting a lot of material even though it has an acceptable quality level; a selected risk factor. β = probability of accepting a lot of material even though it has an unacceptable quality level; a selected risk factor. Burr (6:402).

This according to Belz (3:169-170), Walpole and Myers (33:228-230), and others, is a Type I error, or an error of the first kind, it's probability being α. A mathematical function which indicates the probability α of rejecting H_o for various values of the parameter under consideration is called a power function, and a graph of the function is called a power curve (15:92). An error of the second kind, or Type II error, arises when nothing is said about H_o although the value of the statistic (μ_o in the example above) has changed. In other words, accepting the lot even though it is not good. This error has a probability β (3:170, 33:230-231). An operating characteristic (OC) function is a mathematical expression stating the probability of accepting a process (or lot) as a *function* of the population (or lot) parameter. If the parameter is the mean (or average) and H_o (null hypothesis) is $\mu = \mu_o$ (see Figure 2-4) and the process is to be accepted when the sample mean falls between:

$\bar{X}_L$ = Lower limit for means

and

$\bar{X}_U$ = Upper limit for means

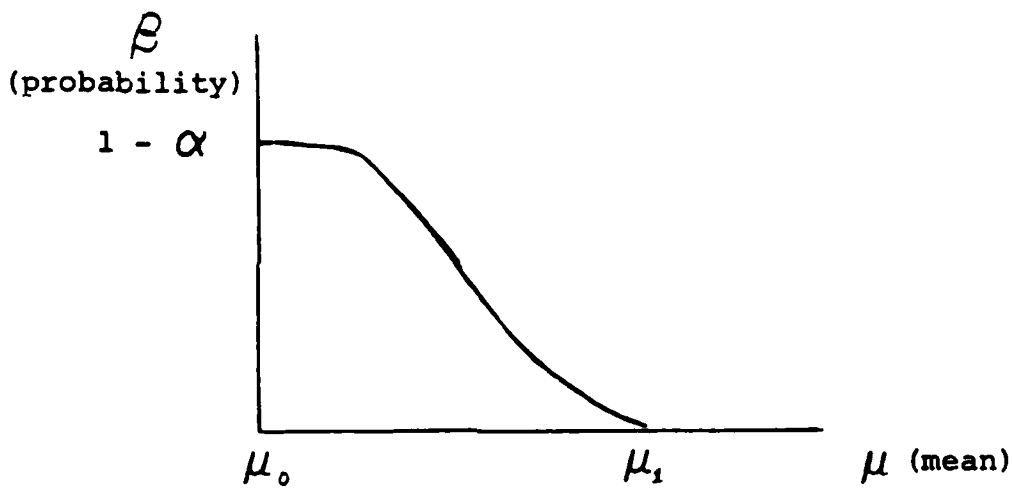
then the OC function is

$$\beta(\mu) = \Pr\ (\bar{X}_L \leq \bar{X} \leq \bar{X}_U \,|\, \mu) = \int_{\bar{X}_L}^{\bar{X}_U} f(\bar{x})\, d\bar{x}$$

An operating characteristic curve graphs the OC function and is thus one way of summarizing a process (or lot) acceptance

FIGURE 2-4:

Operating Characteristic (OC) Curve
In Definitional Form



Operating Characteristic (OC) Curve
In Definitional Form

H_0: (null hypothesis) $\mu = \mu_0$ (σ_x known)

H_1: (alternate hypothesis) $\mu = \mu_1 > \mu_0$

μ = mean of population

μ_0 = null hypothesis value

μ_1 = alternative hypothesis value

σ_x = standard deviation

α = P(reject $H_0 \mid \mu = \mu_0$)

β = P(accept $H_0 \mid \mu \neq \mu_0$)

This curve describes the probability of accepting H_0 for various H_1- values, for fixed α and n (15:184).

sampling plan. In quality control work the OC curve is customarily used versus the power curve. The two curves are related through selection of the null hypothesis (H_o), however. If H_o is that the lot is good, one rejects the lot when rejecting the hypothesis, and the operating characteristic curve is the power curve inverted. On the other hand, if the hypothesis is that the lot is bad, one accepts the lot when rejecting the hypothesis, hence the two curves (power and OC) are identical (8:92). This is presented graphically in Figure 2-4.

While the operating characteristic (OC) and the OC curve are used to design sampling plans, they are also the best-known devices for judging the efficacy of a control chart (8:257). The use of OC curves to describe quality control charts will be developed later in this report.

Quality Control Charts

As stated previously, quality control information is useful only if management can understand and use the information as a basis for making decisions. The most comprehensive display of quality information is attained through use of quality control charts.

> A control chart is a statistical device principally used for the study and control of repetitive processes. . . . Shewhart suggests that the control chart may serve, first, to define the goal or standard for a process that . . . management might strive to obtain; second, it may be used as an instrument for attaining that goal; and third, it may serve as a means of judging whether the goal has been reached (9:337).

Thus, the control chart can be used in all phases of the industrial process (see Figure 2-1) to improve quality. In any product or process some variation in quality is unavoidable. The theory behind the quality control chart originated by Dr. W. A. Shewhart is that this variation can be divided into two categories, random variation and variation due to assignable causes (35:42). Assignable causes are those over which we have some degree of control. Random variation is the result of many complex causes over which we have little or no control.

The basic idea of a Shewhart control chart[10] is simple. Groups of size "n" are drawn from a process (or from incoming lots of material) at regular intervals and measurements of some statistic(s) of quality are made. These measurements are plotted as ordinates on a chart provided with a center line (the average) and a pair of parallel control lines (the upper and lower control limits), as in Figure 2-5. This provides a chronological graphical comparison of actual product-quality characteristics with control limits.[11]

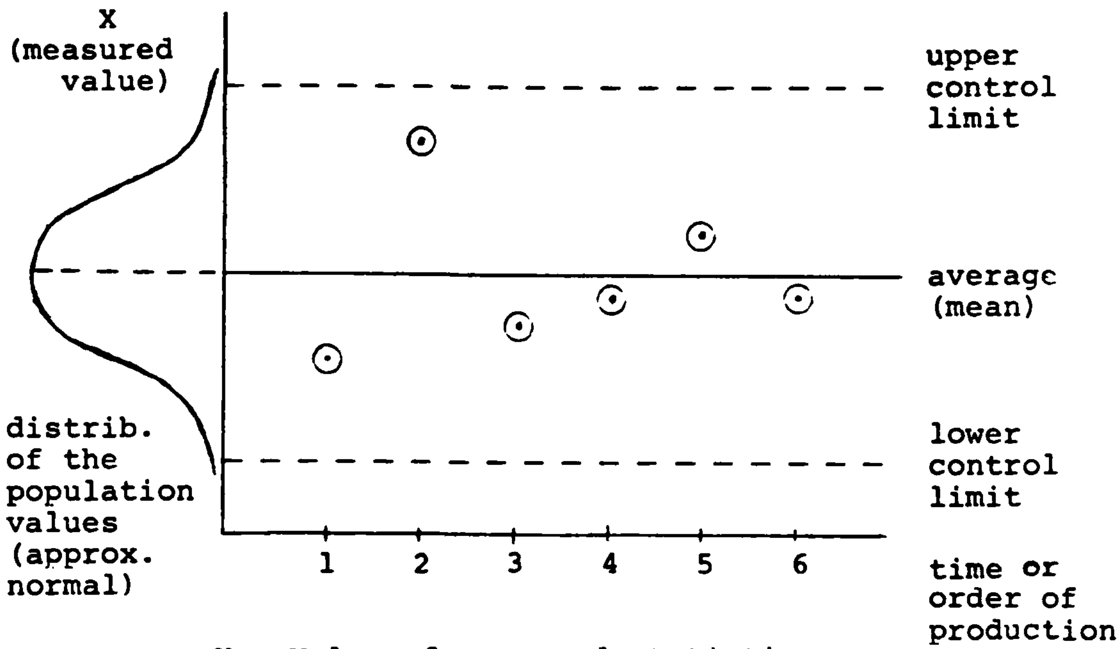
---

[10] Throughout the literature the term control chart is used to describe the Shewhart control chart. The author, throughout the remainder of the report, will do likewise. See Burr (6:92) and (7:29).

[11] Control charts can be developed for both measurement sampling plans and attribute (go/no go, pass/fail, etc.) plans. This report will deal primarily with the measurement control chart although in most cases, the same procedures apply for either.

FIGURE 2-5

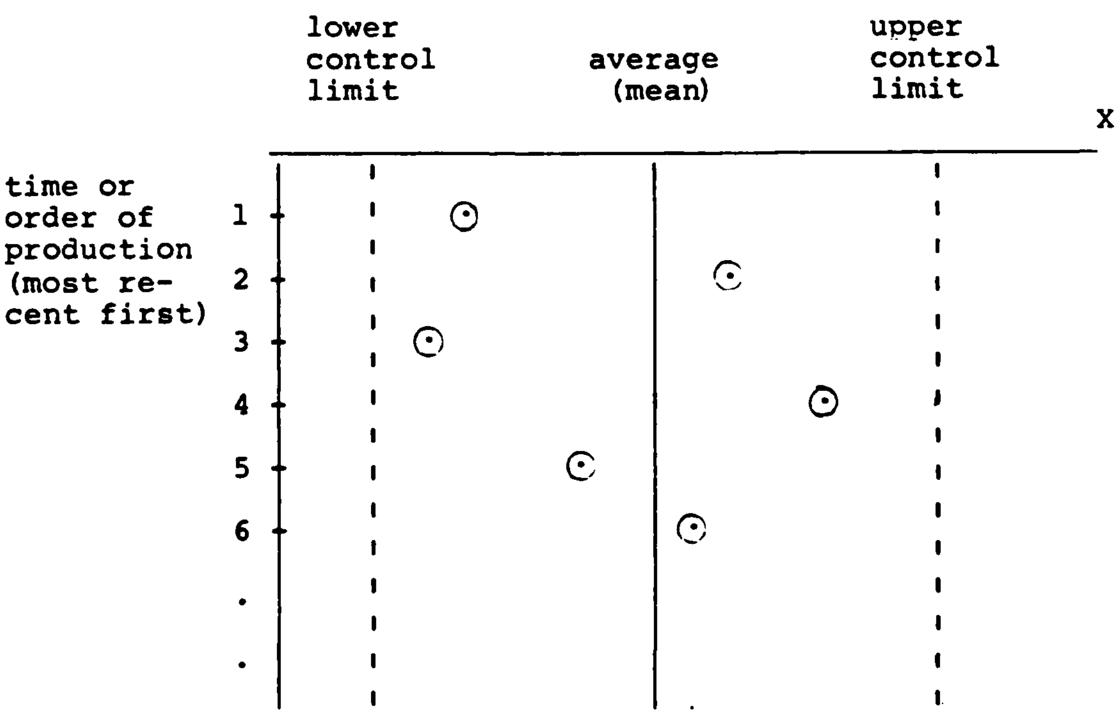
Theoretical Basis of Control Charts



X = Value of measured statistic

= Plotted Value

Computer-produced control charts to be developed in this report are of the following theoretical basis:



Suppose, for example, that one statistic (variable) is measured by testing an item. Assume that this variable is normally distributed under a state of statistical control. The presence of assignable causes of variation would then show up on the data as variation outside the usual range (usually $\pm 3\sigma$ of the average--this will be discussed later) for a normal variable. This can usually be attributed to a change in either μ or σ of the normal distribution for the measured variable. Thus, plotting estimates of the population mean ($\bar{x}$) and standard deviation (s) from the sample group n can be used to determine if the process (or lot of incoming material) is "in" or "out of control" (35:43). If all points fall within limits, the process is probably "in control." If not, the reverse is probably true.

The question of normally distributed data was addressed earlier in this report, and must be mentioned again. Control chart theory assumes that the distribution of observations (measurements) is approximately normal. Even if the population of observations is somewhat non-normal, the distribution of means of observations of sufficient sample size drawn from the population, will exhibit nearly normal behavior according to the central limit theorem (12:47). The normal curve drawn on the left of the ordinate axis of Figure 2-5 represents the distribution of all samples taken.

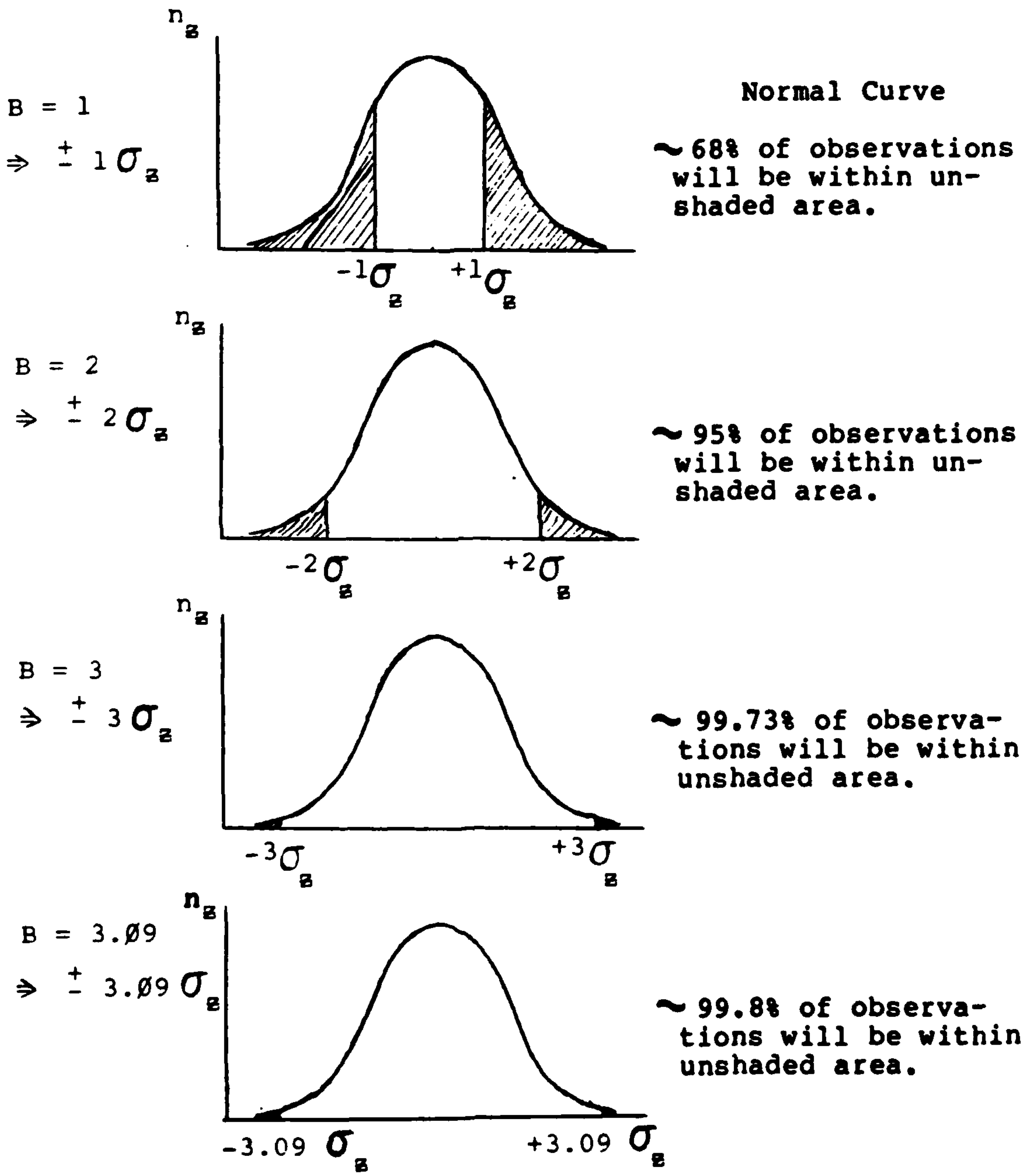
Figure 2-5 is representative of the distribution of all samples taken.

The center line of a control chart for a statistic corresponds either to a given value or, more commonly, to an estimate (perhaps an average) obtained from observed data. The control lines (or limits) are placed symmetrically relative to the center line at distances based on the estimated standard deviation of "z," where "z" is the value of a random variable having the standard normal distribution; $z = (x-\mu)/\sigma$ (18:105-6, 487). Shewhart, based on his experience, chose 3 times (B=3) the standard deviation of z for his charts, yielding the term "three-sigma limits" (3:293-4). The choice of a factor to use for setting up control limits depends on the amount of risk (or cost) in looking for an assignable cause when none is present and the cost of not looking for an assignable cause when one is present. The use of "three-sigma limits" is predominant practice. Under many situations, other values may apply.

Figure 2-6 indicates the effect varying the value of B has on risk. The tighter control limits presented by B = 2 represents a 5% risk of rejecting a lot (and/or declaring a process out of control) when only variation due to chance exists. This may be acceptable if cost of rework/replacement/adjustment is low, but may not if costs are high. Two-sigma limits may, however, be used as warning limits to indicate an approach to the control limits. The question of how many points must be outside the control limits for the

FIGURE 2-6:

Effect of Change of Proportionality Factor (B) on Control Limits



process (or lot) to be "out of control" is of interest. Cowden (8:155) indicates that according to research conducted by the American Standards Association there is strong evidence that a process is out of control if at least 2 of 35, or at least 3 of 100, points of the control chart fall outside the 3-sigma control limits.

Because of lack of knowledge of the exact distribution of the population from which samples are taken, significant reliance cannot be placed on precise probability calculations for determining if a process is in control and the control chart should be considered only a diagnostic device with final judgments (sentencing) relying on other statistical techniques. Cowden (8:155) suggests the following indicators of lack of control.

1. One point far outside a control limit.
2. Several points close to a control limit.
3. A peculiar pattern or arrangement of points, even though none is close to a control limit.

The type of control chart to be used is based on a number of factors. These include the sizes of the sample and overall populations, whether standard deviation is known, and whether or not there is a natural grouping of product, such as shift change, crew change, a certain number of items in each shipment, as in the case being studied in this report, a certain number of items produced from a "melt" of materials, or tests being taken out of multiple positions of a single test object.

Recalling basic probability and statistics indicates that the arithmetic mean, $\bar{X}$, is the most significant single statistic that can be used to describe a distribution (25:8). This indicates that a control chart tracking the average of measurement over time would be of great value. Such a chart, however, gives us no indication as to how such measurements vary about the mean or average. There must be relative uniformity of variation and an absence of variation beyond the limits allowable. Of the numerous available measurements of variability, the most commonly used in quality control according to all references are the standard deviation (or variance) and the range, the difference between the highest and lowest values. Which of these to use is an item of contention among sources. Lester (17:53) advocates the use of range for n (number of observations in the average) $<$ 10. Cowden (8:249) recommends use of standard deviation for n $>$ 12, as does Duncan (9:401), while Samson, Hart and Rubin (25:9) state the range is a suitable statistic. This is due to the significant effect sample size has on the range since there are more chances for extremely high or low values. The standard deviation is only negligibly affected by sample size. The range can be used as a relatively stable measure of variability when one can average a series of ranges (17:301). The simplicity of the R-chart, a plot of the range of each data set used to determine $\bar{X}$, however, is recognized by all sources and all

advocate use of it to make less complicated explanation to managers and other control chart users.

While charts for individual measurements can be constructed, they are not normally used in industry (8:226). Such charts can provide "something" from such meager data as measurements taken once a day, a week, a year, etc., that would require an extensive period of time to assemble a data base for means ($\bar{X}$) (6:263). They can also be used as aids in interpreting control charts for means and ranges by indicating a cause for a mean to go out of control limits and if items have exceeded specification limits while the mean (average) has stayed within the limits. Such charts must be carefully interpreted if the process (or lot) shows evidence of marked departure from normality as they are quite insensitive to shifts in the process mean according to Nelson (20:172-3) and Duncan (9:400).

All control charts are based on tests of hypotheses and the probability of accepting/rejecting these hypotheses. The $\bar{X}$-control chart provides a good example of this as presented by Kirkpatrick (15:188-189):

H_o (null hypothesis): $\mu = \mu_o$

H_1 (alternative hypothesis): $\mu = \mu_1 \neq \mu_o$

The following relationships apply:

1. If H_o is true, the X_i-population of measurements is distributed with mean μ_o and variance σ_X^2

2. All possible samples of size n from the X_i-population generate an $\bar{X}_j$-population of mean values where

$$\sigma_{\bar{X}}^2 = \frac{\sigma_X^2}{n}$$

3. Thus, if H_o is true, the $\bar{X}_j$-population is distributed with mean μ_o and variance $\sigma_{\bar{X}}^2$.

4. If the X_i-population is normal, the $\bar{X}_j$-population is normal. If the X_i-population is not normal and the sample size n is sufficiently large, the $\bar{X}_j$-population is approximately normal.

If X_i is a random variable normally distributed with mean μ_o and variance σ_X^2, then

$$P(\mu_o - 3\sigma_X \leq X_i \leq \mu_o + 3\sigma_X) = 0.9973 \qquad (1)$$

and

$$P(\mu_o - 3\sigma_{\bar{X}} \leq \bar{X}_j \leq \mu_o + 3\sigma_{\bar{X}}) = 0.9973 \qquad (2)$$

Probability (2) is the basis for the $\bar{X}$-control chart shown in Figure 2-7. The ordinate axis indicates $\bar{X}_j$-values. The abscissa axis indicates sample numbers 1, 2, ..., j, ..., k. The lower control limit (LCL) corresponds to $\mu_o - 3\sigma_{\bar{X}}$ and the upper control limit (UCL) to $\mu_o + 3\sigma_{\bar{X}}$.

Thus the $\bar{X}$ chart is a hypothesis test where

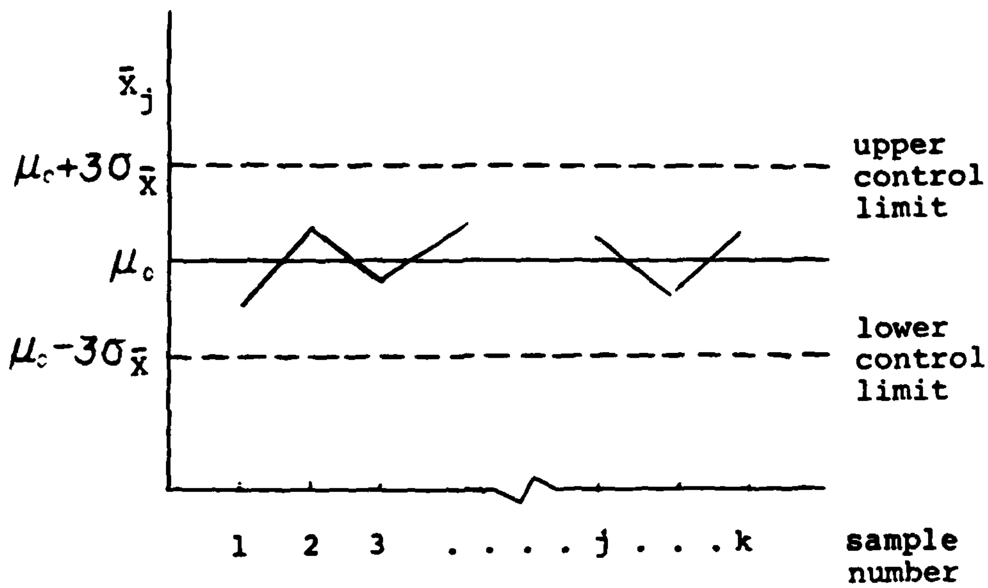
H_o: process in control at quality level μ_o

α = P(reject H_o, H_o true) = 0.003.

In some cases, fixed values for the mean (or center) line and control limits of a control chart are provided or at least the standard deviation and mean are known and used to construct the control chart. This method is usually applied to data from a process that has a long history of

FIGURE 2-7:

$\bar{X}$ CONTROL CHART



Tests the Hypothesis H_o: Process in control at quality level μ_o

α = P(reject H_o; H_o is True) = 0.003

being in control. In the case of this research, these population parameters are not available and the recent past data will be used to estimate these values. As Burr states (6:112), "We let the process do the talking." The control limits and center line can then be determined using these estimates.[12]

For the $\bar{X}$-chart, consider a variable (measurement) "X" that is assumed to be normally distributed (discussed previously in this chapter) with mean "μ" and variance "σ^2." Samples of uniform size "n" are taken at regular intervals and the sample mean

$$\bar{X} = \frac{\sum_{i=1}^{n} X}{n}$$

is taken to be used as the charted statistic. Since by assumption

$$\bar{X} \text{ is } N(\mu, \sigma^2/n)$$

the control chart is specified by a center line at ordinate value

$$\bar{\bar{X}} = \frac{1}{k} \sum_{j=1}^{k} \bar{X}_j$$

$$k \text{ usually } \cong 25$$

---

[12]Burr (6:112-3), Kirkpatrick (15:190-1), Belz (3:299-300), Fiegenbaum (11:257-8), ASTM Manual STP 15D (1:81-2), *et al*. present similar developments and elements of all used here.

and two control limits at

$$\bar{\bar{X}} \pm \frac{3\hat{\sigma}}{\sqrt{n}}$$

As discussed earlier, the sample range can be used as an estimate of the variance of the sample. An adjustment can be made to bring the sample range closer to sample variance by application of coefficient d_2 that is dependent on sample size. The average range is multiplied by $1/d_2$ to yield an estimated standard deviation

$$\hat{\sigma} = \bar{R}/d_2$$

and the control limits may be written

$$\bar{\bar{X}} \pm 3\frac{\bar{R}/d_2}{\sqrt{n}} = \bar{\bar{X}} \pm A_2\, \bar{R}$$

where

$$A_2 = \frac{3}{d_2\sqrt{n}}$$

Tables of the values A_2 and other values to be used are found throughout the literature.[13]

Range charts were used due to the lack of historical data. Sample standard deviations could be used to estimate variance in place of range if more data was available.

The limits for the range control chart also utilize coefficients to make their calculation simpler with R_o and σ_R unknown:

[13] Two comprehensive tables for values up to n=25 can be found in ASTM STP 15D (1:135-5) and Burr (7:486).

$R_o = E(R) = \text{expected value of } R = \bar{R}$

$\sigma_R = \text{deviation of ranges} = d_3 \hat{\sigma} = d_3 \sigma.$

The control limits are

$$E(R) \pm 3\sigma_r = \bar{R} + 3\, d_3 \hat{\sigma}$$
$$= \bar{R} \pm 3\, \frac{d_3\, \bar{R}}{d_2}$$
$$= D_4 \bar{R} \text{ and } D_3 \bar{R}$$

where $D_4 = 1 + 3\,\frac{d_3}{d_2}$ and $D_3 = 1 - 3\,\frac{d_3}{d_2}$.

Just as the range was used to estimate the estimated process standard deviation for developing control chart limits, it can be used to develop operating characteristic (OC) curves for each control chart. When the process is normally distributed, as we have assumed, we can derive an OC curve for an R-chart that is independent of the mean of the process. The OC function for the $\bar{X}$-chart, however, is dependent on both the mean and the standard deviation of the process. The OC curve for the R-chart will, then, be developed first.

For example, consider an R-chart with $3\sigma_R$ limits as previously defined. Let's assume N=4 and values were determined for the UCL(R) and LCL(R). For any given value of α the probability that a sample value of R is between LCL(R) and UCL(R) is to be determined. Thus, the probability of detecting a shift in σ is yielded by the difference between the probabilities that R will be less than the LCL(R) and greater than the UCL(R), and this difference can be plotted to construct the OC curve. The central line of the

R-chart is R, and the control limits are, as previously determined, D_4R and D_3R or

$$\bar{R} \pm 3 \frac{d_3 \bar{R}}{d_2} = \bar{R} \pm 3d_3\hat{\sigma}$$

The process standard deviation can also be used to develop R-chart control limits, if known.

$$UCL = D_4 \bar{R} \quad LCL = D_3 \bar{R} \Rightarrow E(R) \pm 3\sigma_R = E(R) \pm 3d_3\sigma$$

$$E\left(\frac{R}{\sigma}\right) = d_2 \Rightarrow E(R) = d_2\sigma$$

These lead to

$$\text{control limits} = d_2\sigma \pm 3d_3\sigma = \sigma(d_2 \pm 3d_3)$$

$$= D_2\sigma \text{ and } D_1\sigma$$

since $D_1 = (d_2-3d_3)$ and $D_2 = (d_2+3d_3)$.

Since P_r(R is between LCL and UCL) = $P_r(\frac{R}{\sigma}$ is between LCL/σ and UCL/σ) and since a determination if the new $\hat{\sigma}$ is indicating a shift in σ is being sought, the relation between $\hat{\sigma}$ and σ $(\sigma/\hat{\sigma})$ is of interest.

Set the 3-sigma LCL = $D_1\hat{\sigma}$

and

$$\text{3-sigma UCL} = D_2\hat{\sigma}$$

$$\Rightarrow \quad LCL/\sigma = D_1\left(\frac{\hat{\sigma}}{\sigma}\right) = \frac{D_1}{\left(\frac{\sigma}{\hat{\sigma}}\right)}$$

and

$$UCL/\sigma = D_2\left(\frac{\hat{\sigma}}{\sigma}\right) = \frac{D_2}{\left(\frac{\sigma}{\hat{\sigma}}\right)}$$

Now let $W = R/\sigma$ and the probability statement becomes P_r(R is between LCL and UCL) = P_r(W is between $D_1/\frac{\sigma}{\hat{\sigma}}$ and $D_2/\frac{\sigma}{\hat{\sigma}}$).

A different OC function must be determined for each sample size and, since for n (sample size)<7, D_1=0, only the

probability, for different values of σ, that R is below the UCL is of interest. Selecting various ratios of $\frac{\sigma}{\hat{\sigma}}$ and referring to a chart of values of $W(\frac{R}{\sigma})$ at selected probability points[14] yields Table 2-1. Plotting these yields Figure 2-8.

The OC curve for the $\bar{X}$ chart is derived in a similar manner. We assume that $\hat{\sigma}$ remains constant,[15] and compute the probability that a sample $\bar{X}$ will fall within the control limits as a function of the process average μ or $\bar{X}'$. Assume also that $\sigma = \hat{\sigma}$ the value used when constructing the chart. Then, when $\bar{X}'$ equals the standard for the chart ($\bar{\bar{X}}$ or $\bar{X}''$, when given or determined from past history)

$$P_r\ (\bar{\bar{X}} - 3\hat{\sigma} \leq \bar{X}_i \leq \bar{\bar{X}} + 3\hat{\sigma}) = 0.9973$$

when $\bar{X}'$ shifts to either $\bar{\bar{X}}-3\hat{\sigma}$ or $\bar{\bar{X}}+3\hat{\sigma}$, the

$$P_r\ (\bar{\bar{X}} - 3\hat{\sigma} \leq \bar{X}_i \leq \bar{\bar{X}} + 3\hat{\sigma}) = 0.50$$

In general, if $\bar{X}'$ shifts to $\bar{\bar{X}}+k\hat{\sigma}$, the probability of a point's ($\bar{X}_i$) falling within the control limits will be the probability of a normal-distributed variable's falling above $\bar{\bar{X}}+k\hat{\sigma}-\bar{\bar{X}}-3\hat{\sigma}=(k-3)\hat{\sigma}$. So, if k=2, we have P = Prob(Z>-1) = 1-Prob(Z>1) = 0.84 and if k=4, Prob(Z>1) = 0.16. This leads

---

[14]See for instance Duncan (9:614).

[15]If $\hat{\sigma}$ is variable then the OC function is dependent on both μ and σ and the function must be represented by a surface versus a curve. Research indicated that variation hence, μ and σ remain constant. This topic is treated by Duncan (9:309-315), Cowden (8:270-275) et al.

TABLE **2-1:**

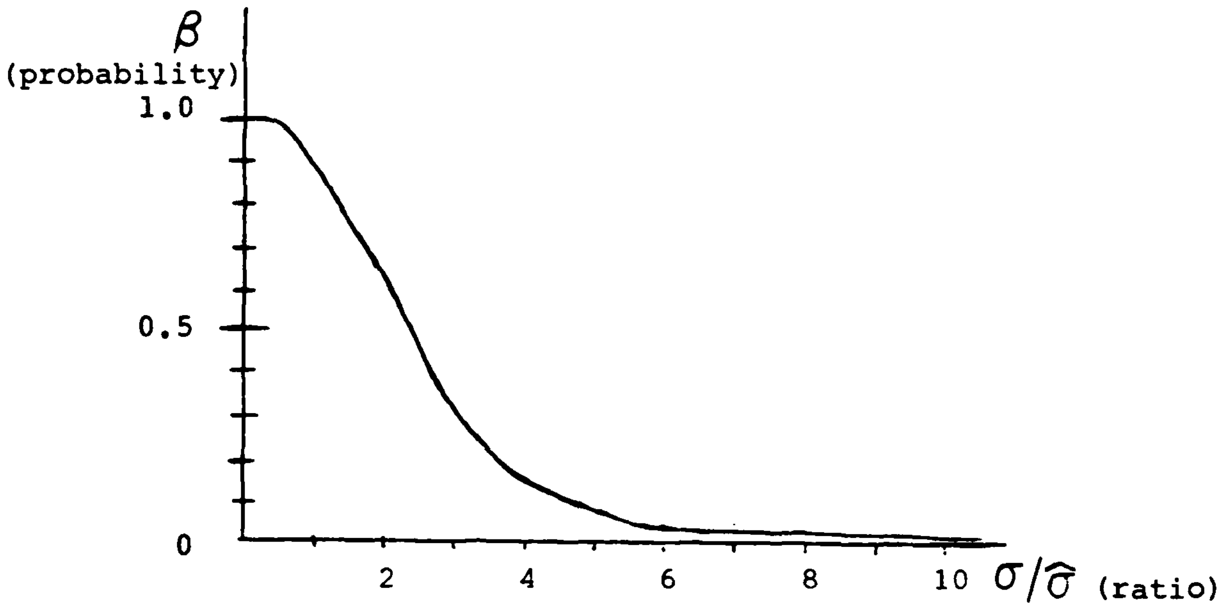
OC of Control Chart for R
Given: 3 sigma control limits

$n=4,\ D_{2_{(n=4)}} = 4.698$

$\frac{\sigma}{\hat{\sigma}}$	$D_2 \div \frac{\sigma}{\hat{\sigma}}$	β
0.5	9.396	*
1.0	4.698	0.995
1.5	3.132	0.881
2.0	2.349	0.656
3.0	1.566	0.312
4.0	1.174	0.160
5.0	0.940	0.085
6.0	0.783	0.055
8.0	0.587	0.024
10.0	0.470	0.013

FIGURE 2-8:

OC Curve for R-chart (n = 4)
(3-sigma control limits, =.003)



H_0 : (null hypothesis) $\sigma = \hat{\sigma}$

H_1 : (alternate hypothesis) $\sigma \neq \hat{\sigma}$

σ = standard deviation of population

$\hat{\sigma}$ = estimated standard deviation of population

β = P (accept $H_0 | \sigma \neq \hat{\sigma}$)

This curve charts the probability of accepting H_0 for various H_1-values, in terms of the ratio of σ to $\hat{\sigma}$ for α =0.003 and n=4(8:268-9).

to Table 2-2 and Figure 2-9[16] (9:308-9).

A control chart, then is essentially an analytical picture of the distribution of the mean and of the variation over time. Numerous researchers and authors have developed or refined computer-generated quality control charts and, no doubt, many others have developed control chart programs for personal computers. Berthoux, Hunter and Pallesen (4:139-149) developed and are utilizing computer-generated charts to monitor Wisconsin Sewage Treatment plants. Sawyer (25:391-395) used computer-generated control charts in a systems approach towards raw product analysis (RPA). This approach utilizes the computer to analyze data to determine out-of-limit conditions and to produce $\bar{X}$ and σ plots for those out-of-limit situations. Reliability engineers analyze the output to determine causes. The aim of this analysis is the achievement of process stability. These two examples indicate that more accurate, up-to-date quality control information can be made available for management decisions through the use of the computer to meet the goal of any quality control program: quality assurance (12:6).[17]

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[16]See Cowden (8:258-9) for another method of plotting the OC function for means.

[17]This term, quality assurance, has come to mean the total set of operations and procedures included within the production system whose goals are conformance of product output to design specifications.

TABLE 2-2:

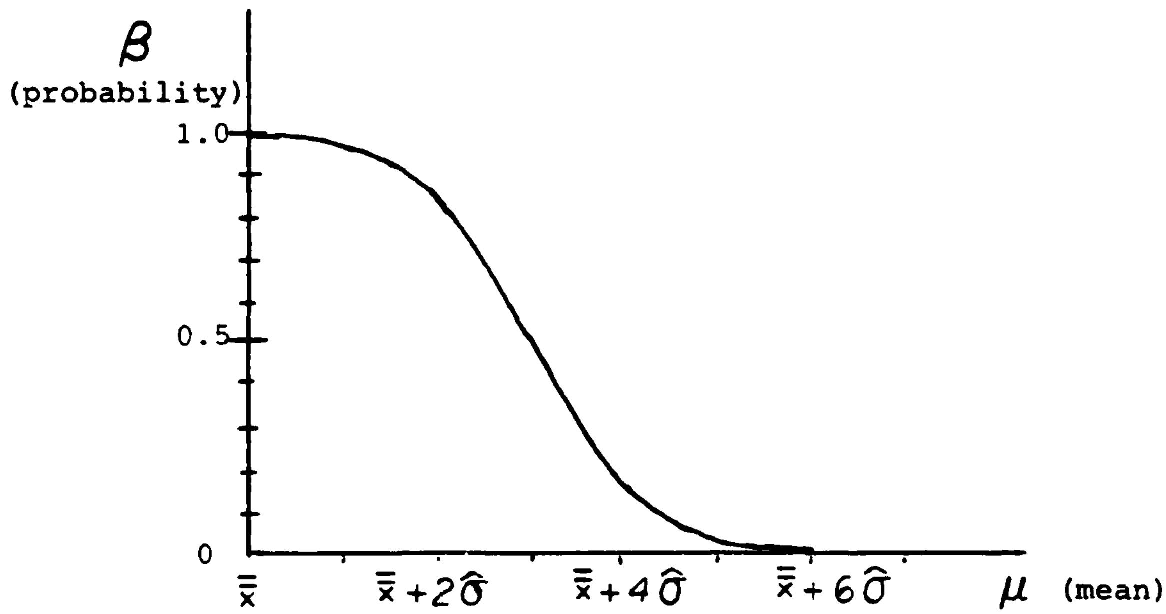
OC of Control Chart for $\bar{X}$
Given: 3 sigma control limits
σ is constant

k*	β
0	0.9973
1	0.9772
2	0.84
3	0.50
4	0.16
5	0.0228
6	0.0027

*k = number of sigmas (σ)

FIGURE 2-9:

OC Curve for $\overline{X}$-chart (n = 4)
(3-sigma control limits, α =.003)



H_0 : (null hypothesis) $\mu = \mu_0 = \bar{\bar{x}}$

H_1 : (alternate hypothesis) $\mu \neq \mu$

σ = population standard deviation

$\hat{\sigma}$ = estimated population standard deviation

$\hat{\sigma}$ is assumed known and fixed = σ

$\bar{\bar{x}}$ = process average

β = P(accept $H_0 | \mu \neq \mu_0$)

This curve describes the probability of accepting H_0 for various H_1- values for α =.003, n=4, and $\sigma = \hat{\sigma}$ = constant (9:309-15).

One of the most interesting, to this author, of available quality control chart programs is one developed in 1969 by Thayer and Storer at the Western Electric Company Engineering Research Center (16:149-152). It provides for reading individual sample values, computing the averages and control limits, and printing of these values on vertical (versus the horizontal presentation of Figure 2.7). This program will be explained further in Chapter 3 of this report and applied to the solution of the problem as stated in Chapter 1.

CHAPTER 3

PROBLEM SOLUTION

What you see is what you've got.--ANONYMOUS

Data Identification and Selection

Data was available from AiResearch for both their testing (CMR data) and for each of the vendors (CERT data). This data was screened and sorted with respect to extent of past history, correlation between vendor and AiResearch data, number of samples taken from each test item, and type of item (casting/forging). The screening indicated that in some cases only one sample was taken from a test item, while in others there were multiple samples taken. This, after reviewing the literature, indicated two separate approaches were required to satisfy the research goals, as stated in Chapter 1; one approach for the multiple-samples case, and another for the single-sample case. Two parts with data histories of minimally adequate length were selected for study; part No. 3072112 (multiple samples) and 3072316 (single samples). Data on these two parts was assembled from manual files to be used as test cases.[18]

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[18]See Table 3-1 for typical data.

TABLE 3-1

Typical Data from Vendor Testing, AiResearch Testing, and Specification Values
(for Part No. 3072112, a turbine disk of forged Astroloy)

IDENTIFICATION						ROOM TEMP TENSILE TEST				
CMR#	DATE	VENDOR CODE[1]	HEAT NO.	SAMPLE ID#	POS ID[2,4]	YIELD PSI	ULT PSI	%E	% RED AREA	
64081	4/77	12112	8-4935 LFZ	8800	1	140.7	189.8	12.0	15.9	CERT[5]
					3	136.4	193.6	19.0	17.5	
					4	134.0	195.2	21.0	19.5	
					5	135.9	196.4	20.0	18.8	
					7	135.9	193.6	19.0	18.2	
64081	4/77	12112	8-4935	8800	3	139.1	206.1	25.0	26.7	CMR[5]
					4	138.7	203.3	22.5	26.0	
					5	135.7	202.7	33.9	24.4	
SPEC. 3,4 MIN VALUES					ALL	130.0	170.0	6.0	6.0	

[1]A Vendor code is assigned to each vendor.

[2]Pos ID indicates the location of the test sample from the test forging; see spec. EMS55389, Pg. 6 (Appendix B).

[3]Taken from spec. EMS 55389 (Appendix B).

[4]The other test item 3072316 is also a forged turbine disk but of Waspaloy under AiResearch spec. No. EMS 55388, Condition B (Appendix B).

[5]CERT results are those from the vendor tests, CMR from AiResearch tests.

Specification Review

In order to determine the performance of the items, a knowledge of the specifications, as established by AiResearch was required. This was accomplished by ordering the applicable specifications from the AiResearch specification library. These are summarized in Table 3-2.[19]

Program Development

Screening and sorting of the extensive amount of manual testing data available indicated the need for a computerized (digital) file system that could rapidly retrieve individual data and be compatible with the quality control charting program that the author envisioned. Review of process approval requests from numerous vendors and the interoffice memos[20] approving these requests indicated that numerous vendors could supply any one part and would be required to submit test results in accordance with the specifications. Thus files for test results of a part would have to include two separate files for each part for each type of test for both the vendor and AiResearch. This was accomplished by assembling the data for each test into two files, one for the vendor CERT data and one for the AiResearch CMR data. They were labeled respectively:

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[19] See Appendix B for copies of specifications.

[20] See Appendix B for copies of these.

TABLE 3-2

Specification Minimum Mechanical Properties for Selected Part Numbers[1]

TEST	Part No. / TYPE / Cond. / Property	3072112 Astroloy A	3072316 Waspaloy B
ROOM TEMP TENSILE	Ultimate (psi)	170.000	175.000
	Yield (0.2%) (psi)	130.000	120.000
	Elongation (% in 4D)	6	12.0
	Reduction of Area	6	15.0

1 SOURCES AiResearch Spec. No. EMS 55388
AiResearch Spec. No. EMS 55389

3072112*VENDOR.

3072316*VENDOR.

and

3072112*CMRARESRCH.

3072316*CMRARESRCH.

and were formatted to include identification of test type and particular data, the vendor (for the CERT files) dates the data covered, the part No., and particular assembly (engine) it belonged to, the number of test items (forgings) and the number of samples taken from each item, the format the data is presented in, and the specification minimum value. The data for each tested property is listed by test item (forging) number and position from the test item (forging). Data from

3072112*CMRARESRCH.

is presented in Figure 3-1.

Reference to AiResearch specification EMS 52476 para 1.4.1 defines a forging lot in terms of two classes (I and II). These are dependent on item size as only so much of the alloy can be processed in a "heat" from which billets are poured prior to forging. In the case of both selected test items, about one hundred (100) items can be made out of a "heat" of material[21] and, as the forging dies have a

[21]This information was gathered from personal interviews with AiResearch personnel during the period Feb-Sept 1979.

FIGURE 3-1

Data from 3072112*CMRARESRCH
For Room Temperature Tensile Tests-Yield

("s" indicates "space")

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LINE

1   ROOM*TEMP. TENSILEsTESTS-YIELDssLADISHsPACIFIC(1/77TO10/78)CMRsDATA
2   s13s3
3   FORMAT(I5.3f10.2)
4   130
5   s2164ss133.9ssssss134.7sssss135.4
6   ss395ss134.4ssssss135.0sssss129.4
7   s2382ss138.9ssssss138.3sssss138.9
8   s2361ss135.6ssssss140.6sssss134.1
9   s3004ss130.43sssss134.8sssss132.4
10  s3443ss133.0ssssss135.3sssss132.7
11  s1011ss133.6ssssss134.4sssss134.6
12  s1048ss133.3ssssss136.6sssss132.4
13  ss800ss139.1ssssss138.7sssss135.7
14  s3337ss133.4ssssss135.4sssss132.4
15  s3368ss134.4ssssss134.4sssss130.3
16  s3040ss132.6ssssss135.8sssss131.2
17  s3046ss132.2ssssss132.2sssss132.6
```

limited life, only about 33 can be made consecutively, yielding 3 lots of approximately 33 items from one heat of material. The number of lots are used to analyze individual (single) tests of an item to be discussed later.

ASTM STP 15D (1:97) indicates that the data in the situation being investigated might be approached in two ways:

1) If there are more than one observation per batch (for instance three samples tested from each test forging, as in the case of part No. 3072112) and the variation within the forging (i.e., between the three tests) is considered small in relation to the variation between the batches (the forgings in this case), then the average of the observations can be treated as an individual observation ($\bar{X}$). Such an approach requires caution because of the within-batch and between-batch effects that may exist. This situation readily fits into the normal control chart situation ($\bar{X}$ and R) described in Chapter 2. Grouping the measurements for a single test item is a rational approach since it is logical to assume that any variations within such a group (or subgroup as it might be termed) would be due on engineering grounds to non-assignable chance causes, but that between the groups (subgroups) the differences (variations) may be due to assignable causes whose presence is suspected or considered possible (1:76).

This assumption, since there is little knowledge of the population, is subject to testing.

2) In the instance of individual measurements (where only one test sample is taken from each test item (forging)), the use of control charts for individual measurements is of benefit. Of particular interest is grouping the individual measurements into subgroups of a rational size and utilizing these subgroups to determine range values for calculation of control limits, i.e. giving some indication of population variation (1:76). Predicating the selection on previous discussion in this chapter leads to $n = 3$ as the rational subgroup size.[22]

Thus, the use of quality control charts are of value in analyzing the data, thereby verifying the decision reached by AiResearch personnel (Chapter 1) and indicating a quality control system that is outlined in Figure 3-2. Analysis of this QC system indicated the need to fulfill the following program requirements.

Two basic programs were required, the first (Program A) being a program to transform the historical data (test results), either individual measurements or group data into required statistical values such as mean ($\bar{\bar{X}}$, $\bar{X}$ or $\bar{R}$), control limits, squares of differences, averages, etc., test the

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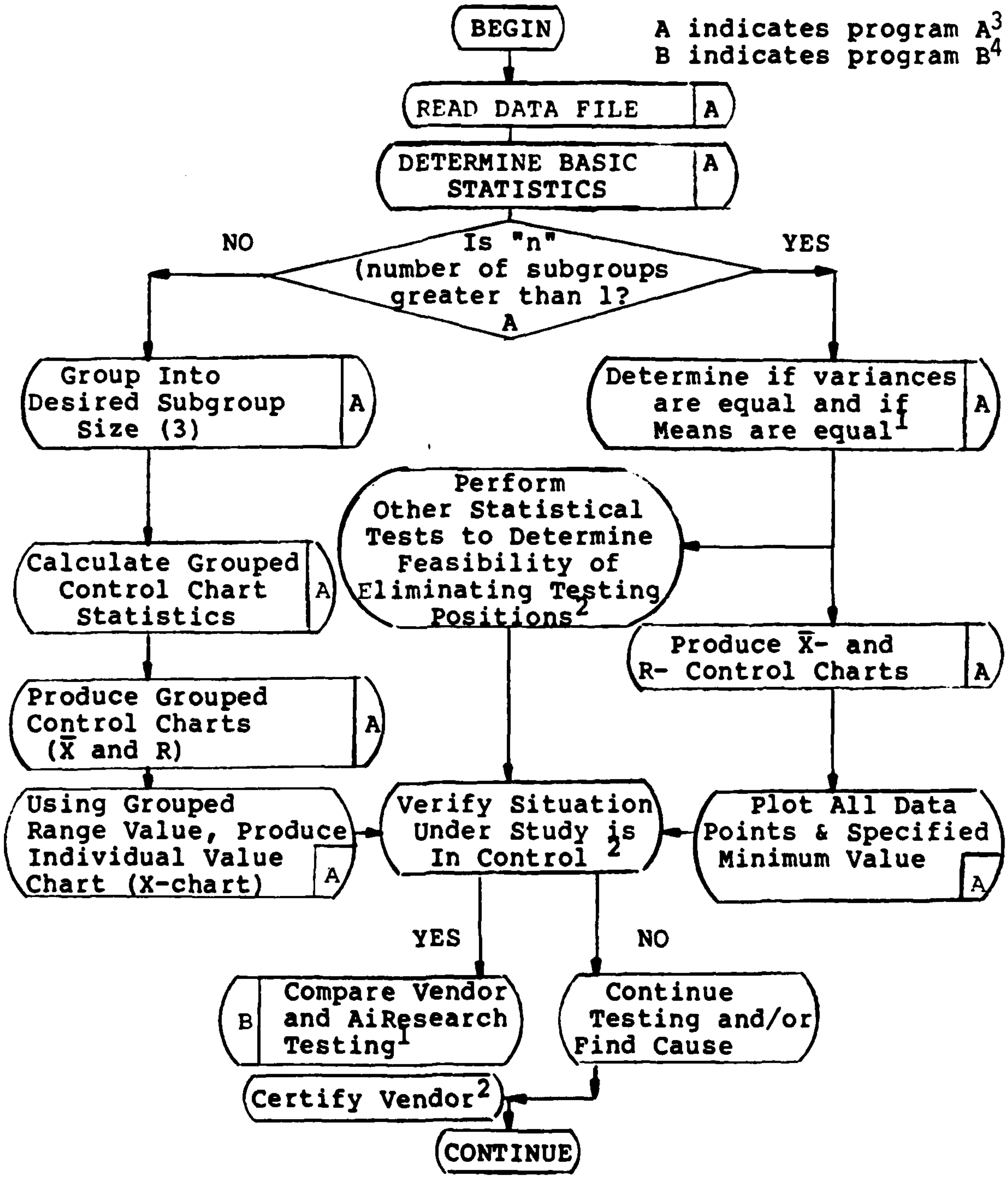
[22]This could be termed a type of "Grand Lot" scheme of sampling with the sublots (of approximate size 33) regarded as part of the larger lot of 100 (6:347).

FIGURE 3-2

Casting/Forging QC System Flow Chart



[1]Computer program to calculate statistics for quality assurance (QA) personnel.
[2]This manual operation performed by QA personnel.
[3]Program A is the QC-chart program in this report.
[4]Program B is the T-star program in this report.

data for correctness in assumptions such as equality of means, variances, etc., and present it in traditional quality control chart form for rapid management assimilation and decision making. The type of charts to be presented include X-,[23] $\bar{X}$-, and R-charts.

The second program (Program B, Figure 3-2) was to test the hypothesis:

H_o: Vendors Testing Results ≡ Company Testing Results

Through use of an appropriate test, such as

$$T^* = \frac{\bar{D} - d_o}{S_d / \sqrt{n}} \; ; \; \nu = n - 1$$

where T^* = T - distribution statistic

n = number of paired observations (Test items)

S_d^2 = variance of the differences =

$$= \frac{n\left(\sum_{i=1}^{n} d_i^2\right) - \left(\sum_{i=1}^{n} d_i\right)^2}{n(n-1)}$$

d_i = individual pair differences

$$\bar{D} = \frac{\sum_{i=1}^{n} d_i}{n} = \text{mean difference}$$

ν = degrees of freedom

d_o = tested difference = 0

μ_D = mean of the population of differences

H_o: $\mu_D = D_o = 0$ in this case

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[23] For the individual and multi-measurement situations alike.

Assume samples are dependent and paired as they are in our case, since they come from the same casting.

These programs would also have to produce statistical data to enable rapid, accurate calculation of the manual testing necessary.

Other requirements, requested during interviews with AiResearch personnel (27:1, 36:1), included making the system comprehensive and effective, but not overly complicated, so that personnel at any corporate level could load data, execute the program, and make simple changes as the situation warranted. In this way, meaningful data could be presented to the head of the Quality Assurance Section for decision making and further analysis to include calling for further testing, vendor certification, elimination of testing. etc.

The selection of a computer language for writing the programs was explored. Three factors, a thorough understanding of the language by AiResearch personnel and the author, adequate computer facilities, and previous programs for plotting control charts, led to the selection of FORTRAN IV.

Initially, the program for plotting $\bar{X}$- and R- charts developed by Thayer and Storer (16:149-152) was evaluated for use. While it performed well at figuring the required statistics ($\bar{\bar{X}}$, $\bar{R}$, control limits) and plotting the values, it had little flexibility and could not perform any more detailed statistical tests. To alleviate this shortcoming, attempts were made to utilize this program along with

statistical programs that were available on the AiResearch computer. The data transformation between the two programs was a monumental task and, after repeated attempts, this approach was abandoned in favor of devising a program or programs that would fit logically and efficiently into the QC system that was outlined in Figure 3-2.

The main program (Figure 3-3) was written as a "command" program to read the data, identify and classify it, and direct, according to its classification, that certain operations be performed on it by means of various subroutines. The subroutines were titled according to function and are listed below with a brief descriptive statement of that function:

CHARTS: Produces X-,$\bar{\bar{X}}$-, and R- charts

SCALE: Provides scaling values for CHARTS

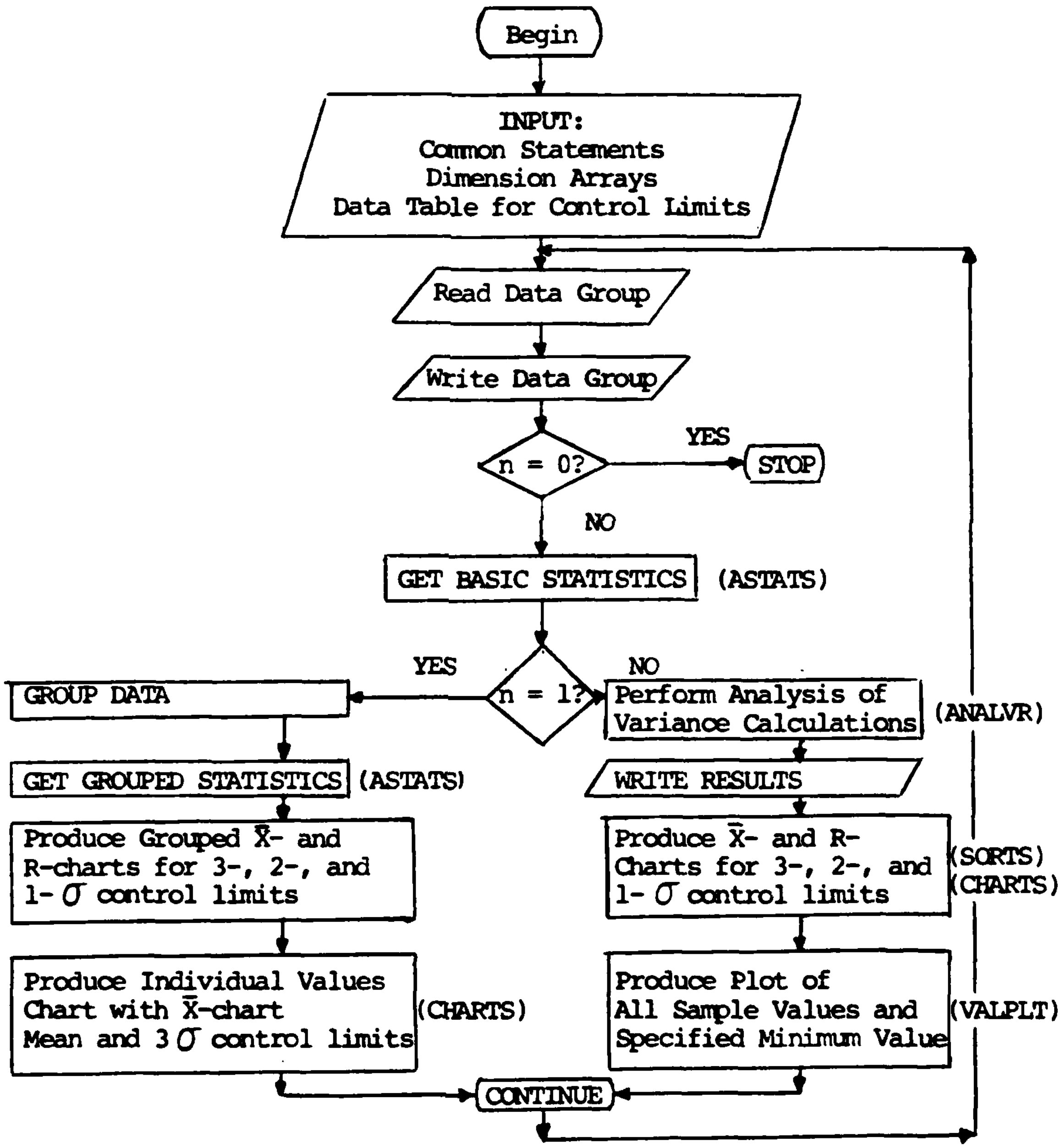
SORTS: Sorts values to find highest and lowest of each subgroup

ASTATS: Determines the sample average, subgroup averages and sample standard deviation of the input data

VALPLT: Plots test results from multiple positions on each casting/forging, if this situation exists. It labels each point with the position in the casting/forging from which the test sample was taken.

FIGURE 3-3

Flow Chart of QCC-MAIN (Main Program)[1]



[1] Subroutine names are indicated in parenthesis to the right of block requiring them.

ANALVR: Analyzes the test data for equality of means and/or variances so that a determination concerning continued testing frequency can be made. Note: This is a general analysis of variance that can be used for other applications.

Main Program

The main program is charted in Figure 3-3. As stated previously, it functions as a "command" program to handle the data. Initially it identifies the data as being individual measurements or grouped measurements. For individual measurements it directs that these be grouped in three's (n = 3, as determined above), necessary statistics and control limits be calculated, and the grouped $\bar{\bar{X}}$- and R- charts be produced. A final treatment of the individual measurement data is to plot the individual data on an $\bar{\bar{X}}$-chart using the grouped $\bar{\bar{X}}$ and control limits.

In the case of the grouped data, the main program directs that the basic statistics be calculated, an analysis of variance (ANOVA) be calculated (to include a One-Way ANOVA, a Two-Way ANOVA, the Cochran's test of variance homogeneity statistic ("G"), (8:159-160) and sufficient statistical data to perform the Duncan multiple range test (18:352-3) , production of $\bar{\bar{X}}$- and R- charts and a plot of all the data points for each test casting/forging along with the minimum specification value.

This program also allows for input of control limit values if these are known from past history and for suppression of printing of means and ranges if the user wishes to exercise either of these options.

ASTATS

Subroutine ASTATS, charted in Figure 3-4, provides statistics necessary for calculation of the control limits, mean lines, and preliminary values for analysis of variance. As depicted in the flow chart of the main program (Figure 3-3) it has been designed with some inherent flexibility as shown by its being used twice for producing the individual measurement charts.

Important values used in ASTATS and their definitions are:

SUM = Total number of items for the population = n.k

$$SUMX = \sum_{i=1}^{n} X_i \quad \text{for each subgroup J}$$

$$SUMSQ = \sum_{i=1}^{n} X_i^{\ 2} \quad \text{for each subgroup J}$$

$$SUBAR(J) = \frac{SUMX}{n} \quad \text{for each subgroup J} = \bar{X}_j$$

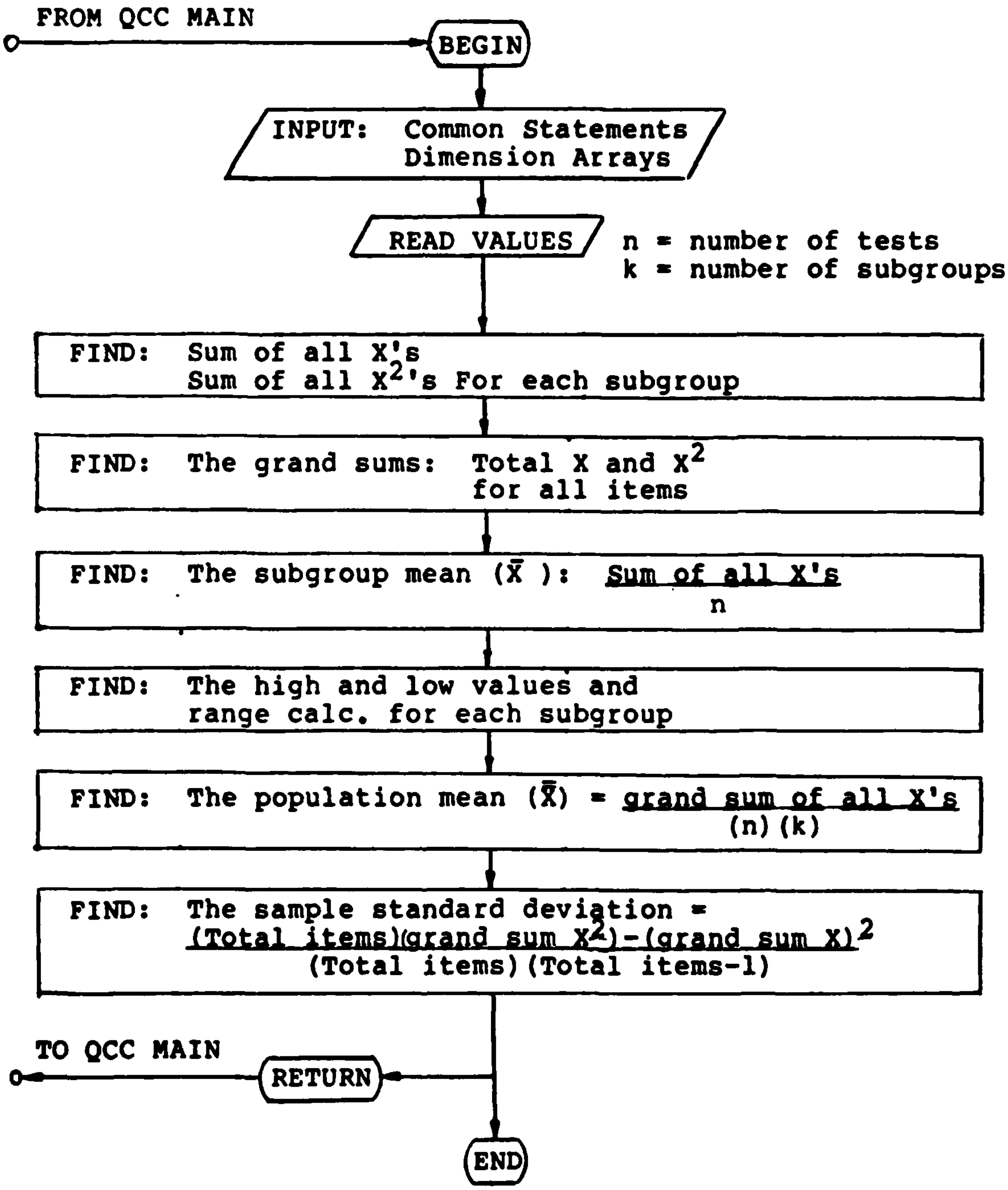
$$RANGE(J) = HIX_i - LOWX_i \text{ for each subgroup J} = R_j$$

$$STOT = \sum_{i=1}^{n} \sum_{j=1}^{k} X_{ij} \quad \text{for the population} = n \cdot k$$

XBAR = STOT/SUM = population mean

FIGURE 3-4

FlowChart of QCC-ASTATS (Preliminary Statistics)



$$\text{SQRTOT} = \sum_{i=1}^{n} \sum_{j=1}^{k} x_{ij}^{2} \text{ for the population}$$

$$\text{SSDEV} = \left[\frac{(\text{SUM})(\text{SQRTOT}) - (\text{STOT})^2}{(\text{SUM})(\text{SUM} - 1)} \right]^{\frac{1}{2}}$$

= sample standard deviation for the test population.

CHARTS

This subroutine, flowcharted in Figure 3-5, plots the data values desired, either x, $\bar{X}$, or R, in vertical quality control charts to include control limits, average value, minimum spec. value, test item number, statistic value being plotted and scale values used. It also has inherent flexibility as it is employed to produce 3-, 2-, and 1-sigma control charts and can handle user-specified limits when applied.

Important values used in CHARTS and their definitions include

NNDEV = Desired control limit σ (sigma)

RBAR = $\bar{R}$

UCL = Range Chart Upper Control Limit = $D_4\bar{R}$

BCL = Range Chart Lower Control Limit = $D_3\bar{R}$

XBAR = $\bar{X}$

UCLL = $\bar{X}$ - Chart Upper Control Limit = $\bar{X} + A_2\bar{R}$

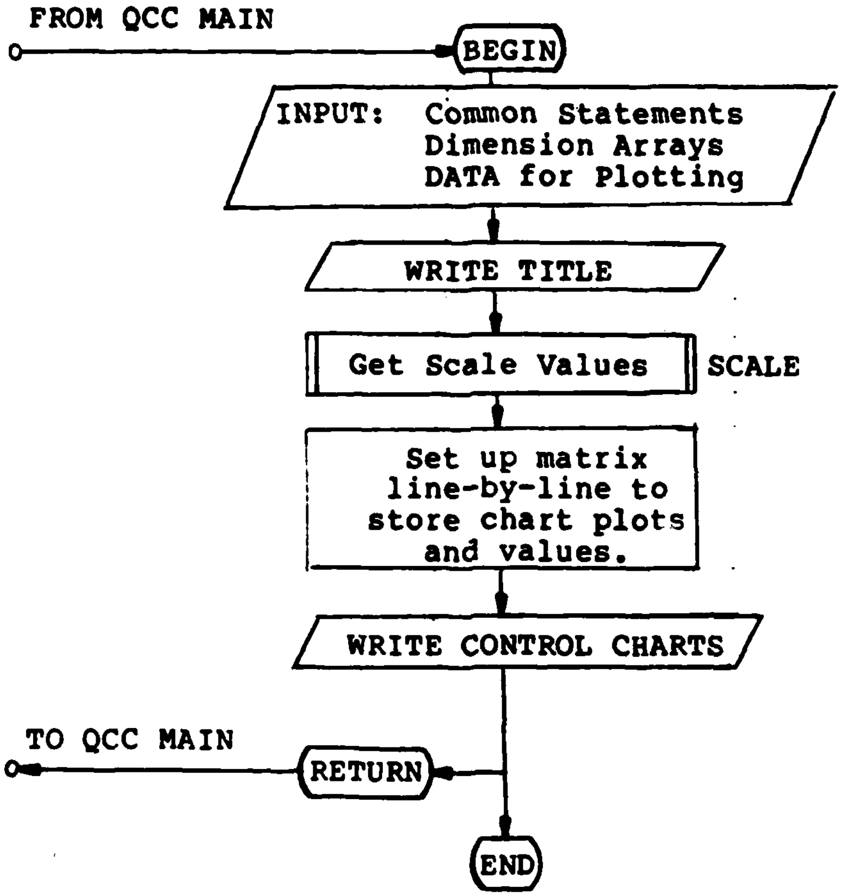
BCLL = $\bar{X}$ - Chart Lower Control Limit = $\bar{X} - A_2\bar{R}$

SP2, DIV, SB = Scaling factors for R chart

SP1, DIVI, RA1, = Scaling factors for $\bar{X}$- or X- chart

FIGURE 3-5

Flow Chart of QCC-Charts
(Plotting of X-, $\overline{X}$-, and R-Charts)



SORTS

This subroutine is used to find the largest and smallest values of the subgroup mean and range to use in the CHARTS subroutine. It merely sorts through the subgroup ranges and means, comparing them initially to the intentionally high and low values and continues to reset the values as it finds larger and smaller values. This short subroutine has good flexibility as it can sort through either range or mean data, and is vital to the program as a whole. No flow chart is presented here, but detailed flow charts of the main program and all subroutines are available in Appendix C.

SCALE

This subroutine determines the scale to be used for the 36-space width, respectively, of the $\bar{X}$- and R-charts. It does so by utilizing the high and low values from the SORTS subroutine to determine the scale and the values that divide the scale into thirds. For example, say

L = Low Value

H = High Value

then the scale would have to cover

H - L = scale

The values to divide the scale in thirds would be

$$L + ((H-L)/3) \text{ and } H - ((H-L)/3)$$

This subroutine also has the flexibility to be used with either means or ranges and, with slight modification, to

divide the scale into whatever increments the user desires. Again, no flowchart is presented here; for a detailed one, see Appendix C.

VALPLT

Subroutine VALPLT is a specialized derivative of the CHARTS subroutine that produces a plot of the test value of each tested position in a sample casting/forging and labels each value with the position from which it came. As in CHARTS, it sets up a line-by-line array to print out a chart of the values within the 101 available spaces. Because it is intended to supplement the $\bar{X}$- and R- charts, it does not utilize the control limits but only the minimum specified value so that the user can detect "below specifications" individual measurements that may (or may not) have contributed to a mean or range value being "out-of-limits." While designed for the specialized case of tests being taken from four locations in the test forgings of part number 3072112, it is easily modifiable to meet user demands. As it resembles CHARTS closely, with the exception of utilizing the scale values determined by SCALE through CHARTS, no flowchart is presented here, although the detailed flowchart is available in Appendix C.

ANALVR

To provide statistical calculations that were not conveniently obtained through available statistical programs, subroutine ANALVR (ANALysis of VaRiance) was designed

to provide the following:

a) Compute statistical values for One-Way Analysis of Variance (ANOVA)

b) Compute "F" value for One-Way ANOVA

c) Compute "G" value for Cochran's test for homogeneity of variances

d) Compute statistical values for Two-Way ANOVA

e) Compute "F" values for Two-Way ANOVA

The one-way ANOVA was selected to test the hypothesis

$$H_o: \mu_{pos_1} = \mu_{pos_2} = \ldots = \mu_{pos_i}$$

$$\text{for } i = 1, 2, \ldots, n$$

where n = number of test positions in a test casting/forging. The statistical model for a case where there are different treatments (positions) for any number of observations (test casting/forging) (See figure 3-6) can be described as (18:337, 19:34, et al.):

X_{ij} = ith, jth observation

$X_{ij} = \mu + \tau_i + \epsilon_{ij}$, for i=1, 2, ..., n and j=1, 2, ..., k

where

k = number of groups (test pieces)

μ = overall mean

τ_i = effect due to treatment

ϵ_{ij} = random error component

Since the treatment (position) observations are not random, we wish to determine the effect, if any, of position of the test sample in the casting/forging or

$$H_o: \tau_1 = \tau_2 = \ldots = \tau_n = 0 \qquad \text{(null hypothesis)}$$

FIGURE 3-6

One-Way Analysis of
Variance Data and Table

DATA:

	Treatment (i = 1, 2, . . ., n)			
Observations replications (j = 1, 2, . . ., k)	X_{11}	X_{21}	X_{31}	X_{i1}
	X_{12}	X_{22}	. . . .	
	X_{13}	. . . .		
	. . . .			
	X_{1j}	X_{2j}	. . . .	X_{ij}

TABLE:

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
Between trtments (positions)	SS_{Tr}	n-1	$\frac{SS_{Tr}}{n-1}=MS_{Tr}$	$\frac{MS_{Tr}}{MS_E}$
Error (within trtments)	SS_E	N-n	$\frac{SS_E}{N-n}=MS_E$	
Total	SS_T	N-1		

with $H_1 : \tau_i \neq 0$ for at least one "i" (alternate hypothesis)

By partitioning the total variability into its component parts, the total corrected sum of squares

$$SS_{TOTAL} = SS_T = \sum_{i=1}^{n} \sum_{j=1}^{k} X_{ij}^2 - \frac{(XTOT)^2}{N}$$

where $N = (n)\cdot(k)$

$$X_{TOT} = \sum_{i=1}^{n} \sum_{j=1}^{k} x_{ij}, \quad X_i = \sum_{j=1}^{k} X_{ij},$$

can be expressed as

SS_T = Sum of squares due to treatment + sum of squares due to error

$$= \sum_{i=1}^{n} \frac{(X_{ij})^2}{n} - \frac{(X_{TOT})^2}{N} + SS_{ERROR}$$

$$SS_T = SS_{TREATMENTS} + SS_{ERROR}$$

$$= SS_{position} + SS_{error} \quad \text{(in this case)}$$

$$= SS_{Tr} + SS_E \quad \text{(see 19:36 for derivation)}$$

and, thus $SS_E = SS_T - SS_{Tr}$

There are: a) N observations (sample values)

b) n levels of treatment ⇒ n-1 degrees of freedom

c) k levels of replication (test castings or forgings) in any treatment (position) ⇒ k-1 degrees of freedom

d) $n(k-1) = N - n$ = Total degrees of freedom for error

A theorem proposed by Cochran (19:37) leads to the conclusion that under H_o

$$F_o = \frac{SS_{Tr}/(n-1)}{SS_E/N-n} = \frac{MS_{Tr}}{MS_E}$$

where MS_{Tr} = Mean square of treatments

MS_E = Mean square of error

follows the $F_{(n-1)(N-n)}$ distribution tables which can be found in many statistics and quality control texts (18:490-491, 19:397-401, and others). This allows us to see if, for various confidence levels (various levels of α), the treatments (positions) are the same. The one-way analysis of variance can be summarized in an ANOVA table such as that in Figure 3-6.

There are occasions when a single point falls far outside of a control limit and the user wishes to determine if such a point is too extreme to be attributed to chance. Cochran's test for homogeneity of variances (8:159-160) compares the variances as estimated by the standard deviation. The statistic g,

$$\text{where } g = \frac{\text{largest } X^2}{\text{sum } X^2} = \frac{\text{largest sample standard deviation}}{\text{sum of all sample std. deviations}}$$

is used to address

$$H_o: \sigma_1^2 = \sigma_2^2 = \ldots = \sigma_j^2, \quad \text{for } j = 1, 2, \ldots, k$$

using the sample standard deviation as an estimation of variance. Tables of g for $\alpha = .05$ and $\alpha = .01$ are available (8:688). This statistical tool can be used to identify bad samples, "back-up" the range chart, and eliminate testing positions.

The two-way analysis of variance (ANOVA) was chosen to test both the treatment and block effect of the model.

X_{ij} = any ith, jth observation

$X_{ij} = \mu + \tau_i + \beta_j + \epsilon_{ij}$ for $i=1,2,\ldots,n$ and $j=1,2,\ldots,k$

where k = number of blocks (test pieces)

μ = overall mean

n = number of treatments (testing positions)

τ_i = effect due to treatment

β_j = effect due to blocks

ϵ_{ij} = random error component

Theoretical data is presented in figure 3-7. The two-way ANOVA tests

$$H_o: \tau_1 = \tau_2 = \ldots = \tau_n = \emptyset$$

and

$$H_o: \beta_1 = \beta_2 = \ldots = \beta_k = \emptyset$$

against

H_1: One of the effects $\neq 0$.

By partitioning the total variability into its component parts as was done in the one-way analysis of variance,

$$SS_{TOTAL} = SS_T = SS_{Treatment} + SS_{Blocks} + SS_{error}$$

$$= SS_{Tr} + SS_{BL} + SS_E$$

$$= \left[\sum_{i=1}^{n} \frac{(X_i)^2}{n} + \frac{(X_{TOT})^2}{n}\right] + \left[\sum_{j=1}^{k} \frac{(X_{\cdot j})^2}{n} + \frac{(X_{TOT})^2}{N}\right] + SS_E$$

and, thus

$$SS_E = SS_T - (SS_{Tr} + SS_{Bl})$$

$$X_{\cdot j} = \sum_{i=1}^{n} X_{ij}$$

While the degrees of freedom are similar to the one-way ANOVA, there are differences:

1) Since there are k levels of blocking $\Rightarrow$ k-1 degrees of freedom

2) This leads to the error degrees of freedom of those for treatment times those for blocks $\Rightarrow$ (n-1)(k-1)

3) Treatment degrees of freedom = n-1

   Total degrees of freedom = N-1

In the same way, the "F" statistic for the one-way ANOVA was determined

$$F_o = F_{Tr}$$

and

$$F_{Bl} = \frac{SS_{BL/(K-1)}}{SS_{E/(n-1)(k-1)}} = \frac{MS_{BL}}{MS_E}$$

where MS_{Bl} = Mean square of treatments

MS_E = Mean square error

The distribution to be used for $F_{Tr} = F_{(n-1),(n-1)(k-1)}$ and for $F_{BL} = F_{(k-1),(n-1)\cdot(k-1)}$ at various levels of confidence.

Use of this method of statistical analysis allows not only testing for treatments, but for blocks as well.

The two-way analysis of variance is summarized in tabular form in Figure 3-7. Subroutine ANALVR, based on the aforementioned equations and testing statistics, was written to provide the desired values in a usable format. This subroutine, flowcharted in Figure 3-8, has the capability of being used in numerous situations requiring only minor modification. A detailed flowchart of this subroutine can be found in Appendix C.

Some important variables used in subroutine ANALVR include:

SQRTOT = Sum of all values squared

STOT = Sum of all values

TRT(I) = Total of values for each treatment (position)

TRM(I) = TRT(I)/n

BLK(J) = Total of values for each block (test piece)

SSPOS(I) = Sum of squared differences for each treatment

TSDEV(I) = Treatment sample standard deviation

SUMDEV = Sum of all TSDEV(I)

FIGURE 3-7

Two-Way Analysis of Variance Data and Table

DATA:

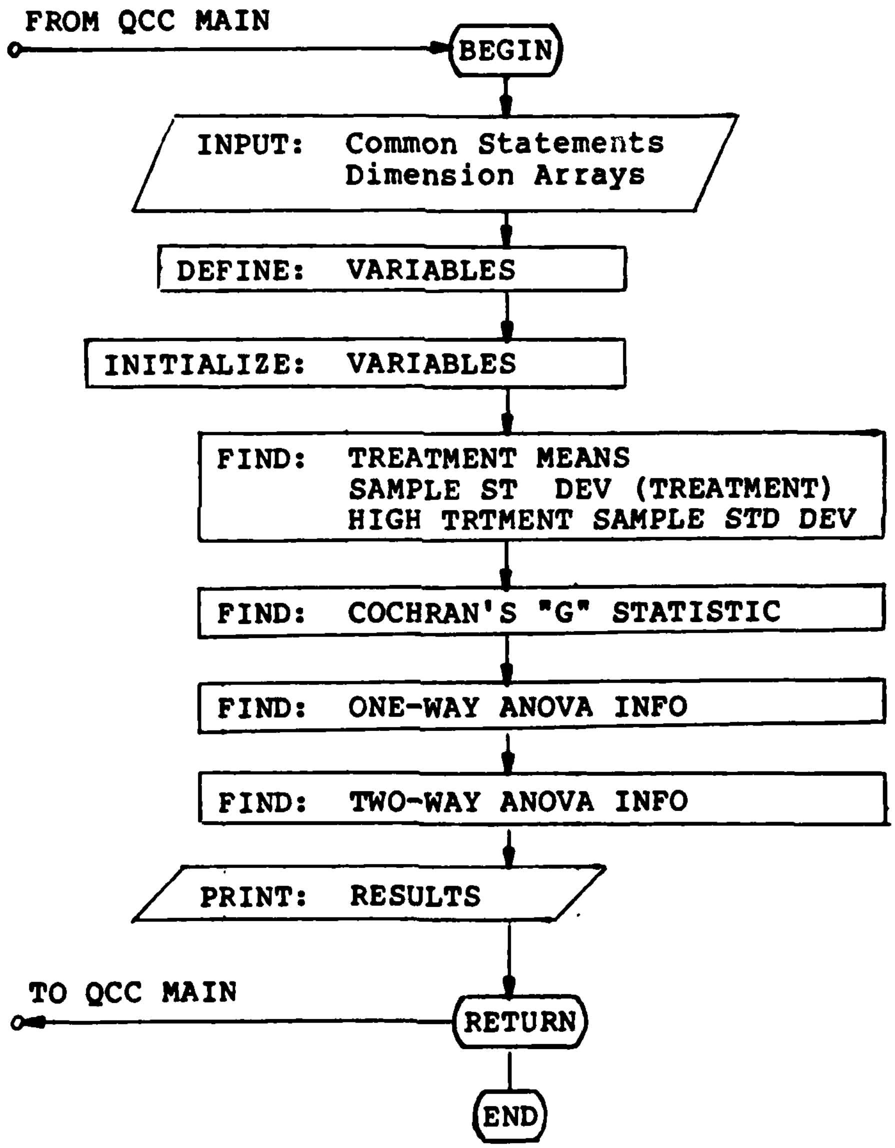
	Treatment (i = 1, 2, . . ., n)
Observations replications (j = 1, 2, . . ., k)	X_{11} X_{21} . . . . X_{i1}
	X_{12} X_{22} . . . . X_{i2}
	. . . .
	. . . .
	X_{1j} X_{2j} . . . . X_{ij}

TABLE:

SOURCE OF VARIATION	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F
Treatment	SS_{Tr}	n-1	$\frac{SS_{Tr}}{n-1} = MS_{Tr}$	$F_{Tr} = \frac{MS_{Tr}}{MS_E}$
Blocks	SS_{Bl}	k-1	$\frac{SS_{Bl}}{k-1} = MS_{Bl}$	$F_{Bl} = \frac{MS_{Bl}}{MS_E}$
Error	SS_E	(n-1)(k-1)		
Total	SS_T	N-1		

FIGURE 3-8

FlowChart of QCC-ANALVR
(Statistical Testing, ANOVA)



DIFSQR(I) = Squared difference between test value and average value for each position

COCRNG = Cochran's "G"

$$= \frac{\text{Highest TSDEV(I)}}{\text{SUMDEV}}$$

SSTRT = SS_{Tr}

SSBLK = SS_{bl}

SSE = SS_E for one-way ANOVA

SSE2 = SS_E for two-way ANOVA

DFTRT = Treatment degrees of freedom

DFBLK = Block degrees of freedom

DFTOT = Total degrees of freedom

DFERR = Error degrees of freedom for one-way

DFE2 = Error degrees of freedom for two-way

AMSE = MS_E for one-way

AMSE2 = MS_E for two-way

AMSTRT = MS_{Tr}

AMSBLK = MS_{Bl}

F = F_o for one-way

F2TRT = F_{Tr} for two-way

F2BLK = F_{Bl}

TSTAR

In order to test the hypothesis

H_o: Vendors Test Results = Company Test Results ,

a program was written to take manually-paired data from both AiResearch and vendor tests of their respective halves of

the test forging/castings and perform the "paired-T" (or T^*) test on the data. This program is flowcharted in Figure 3-9. A more detailed flowchart can be found in Appendix C. Like subroutine ANALVR this program, TSTAR has considerable flexibility as it is not dependent on the main program for data (although it could be used as a subroutine). In this way, any paired, dependent data could be tested against the null hypothesis discussed previously.

Some important variables used in TSTAR include:

NG = ANG

= Number of data pairs

DMU = Value to be investigated by testing H_o

VALCRT = Average value from vendor test

VALCMR = Average value from AiResearch test

DIFF(I) = VALCRT - VALCMR

DIF2(I) = $DIFF(I)^2$

TSTAR = T used to test H_o

NDOF = Number of degrees of freedom

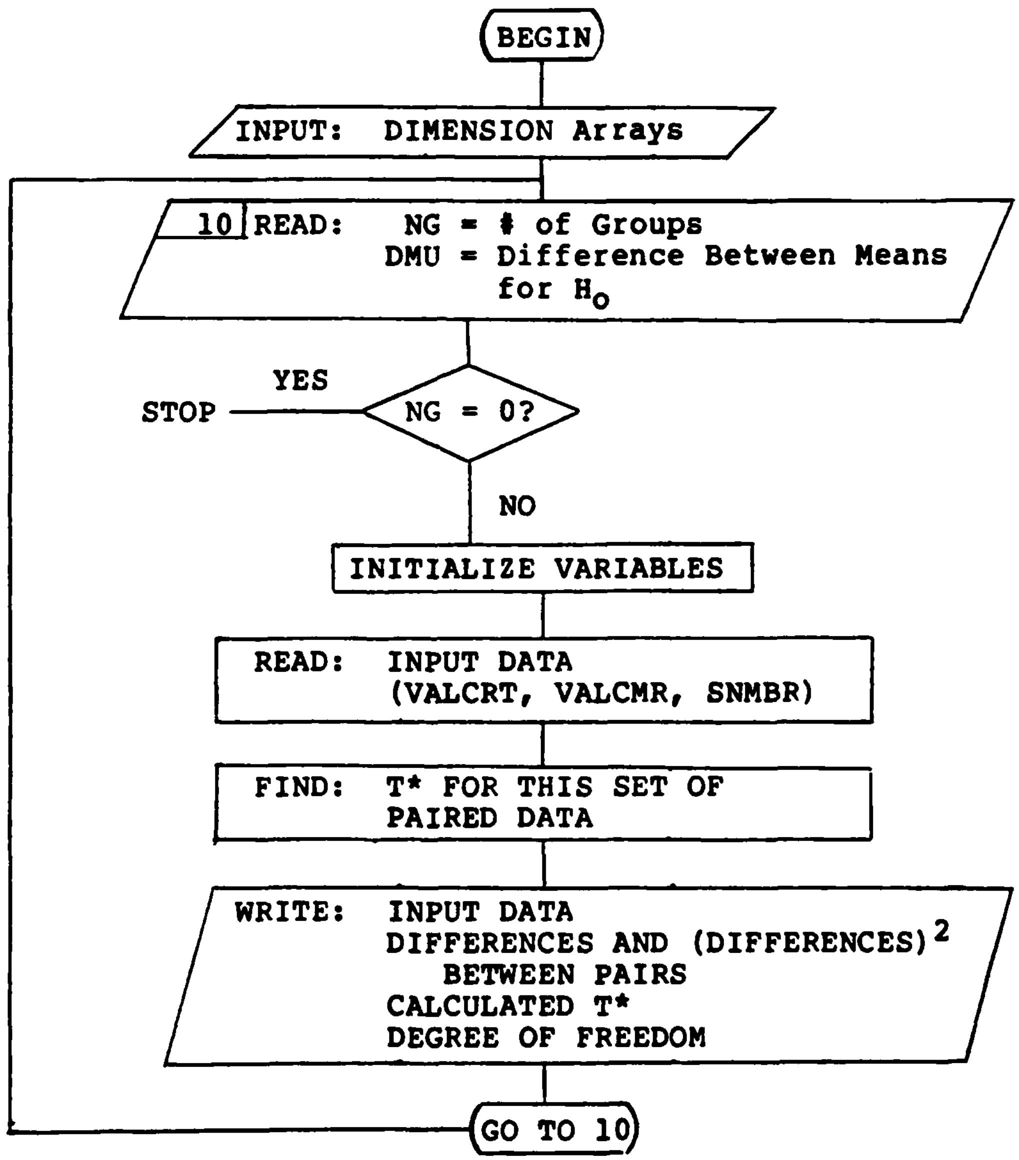
SNMBR = Serial number of casting/forging

Program Testing

The two programs were written and tested using selected data from testing of the two selected forgings. Chapter 4 presents the results of testing the data and discusses their compatibility with the quality control system charted in Figure 3-2.

FIGURE 3-9

FlowChart of TSTAR
(Paired-data T-Test)



CHAPTER 4

PROGRAM EVALUATION

A picture is worth a thousand words--UNKNOWN

Results and Discussion

As stated previously, two forgings were chosen based on the available data as test cases for testing the capabilities of the proposed quality control system in general and the QC charting/statistic programs derived in Chapter 3. In order to present the test cases as concisely as possible, only one test measurement (Tensile test-yield for part No. 3072112 and Tensile test-ultimate for part No. 3072316) will be used to demonstrate the capabilities of the programs. These were selected only because they were the first data sets input for each part and were used to verify the accuracy of the program. The remainder of the tests run are presented in Appendix E for reference.

Part Number 3072112--
Forged Turbine Disk of Astraloy, Condition A

Table 4-1 presents the input data as read by the main program for the vendor certification (CERT) while table 4-2 presents the data for the AiResearch Chemical/Metallurgical report (CMR).

TABLE 4-1

Part No. 3072112 Vendor (CERT) Data

**ROOM TEMP.TENSILE TESTS-YIELD LAC.PAC.(1/77 TO 5/79) CERT
--3072112--TFE731 ENGINE PART DATA

12 4 0 0 0

FORMAT(I5,4F10.2)

FORMAT(4A4)

POS3POS4POS5POS7

NOTE: MOST RECENT DATA IS AT TOP OF THE TABLE.

SERIAL # INPUT DATA BY POSITION

2237	132.20	133.80	132.80	133.20
2164	132.70	137.80	135.10	134.30
395	135.90	137.00	132.70	133.70
2382	137.60	139.60	140.70	138.10
404	137.20	136.40	135.50	136.80
2374	139.50	138.30	142.20	138.70
3015	135.60	135.20	130.80	136.50
3345	138.90	138.50	137.50	139.50
9800	136.40	134.00	135.90	135.90
3040	133.30	131.10	131.30	135.70
3046	132.30	131.60	131.20	136.30
3010	144.30	142.70	141.50	140.20

THE MEAN = 136.21 STAND DEV = 3.30

SUM = 6538.00 SUM OF SQUARES = 891040.89

TABLE 4-2

Part No. 3072112 CMR Data

**ROOM TEMP. TENSILE TESTS-YIELD   LAD-PACIFIC(1/77 TO 10/78)CMR DATA

--3072112--TFE731 ENGINE PART

14 3 0 0 0

FORMAT(I5,3F10.2)

FORMAT(3A4)

POS3POS4POS5

NOTE: MOST RECENT DATA IS AT TOP OF THE TABLE.

SERIAL #	INPUT DATA BY POSITION		
2164	133.90	134.70	135.40
395	134.40	135.00	129.40
2382	138.90	138.30	138.90
2361	135.60	140.60	134.10
3004	130.43	134.80	132.40
3443	133.00	135.30	132.70
1011	133.60	134.40	134.60
1048	133.30	136.60	132.40
800	139.10	138.70	135.70
3337	133.40	135.40	132.40
3368	134.40	134.40	130.30
3040	132.60	135.50	131.20
3046	132.20	132.20	132.60
3010	139.20	138.90	136.50

THE MEAN = 134.71   STAND DEV = 2.69

SUM = 5657.73   SUM OF SQUARES = 762436.59

Note that the CERT data carried 4 testing positions (3, 4, 5 & 7) while the CMR data only carried 3. This was due to AiResearch only conducting (or reporting) tests at three locations while still requiring the vendor to test in four locations. Whether this was a transitory event that occurred while the author was obtaining data, or it was a standard occurrence (perhaps the vendor was working under a different set of testing specifications) was unclear. Another item of note is that there are 14 test samples in the CMR data covering the time period 1/77 to 10/78 while the CERT data contained 12 test samples covering 1/77 to 5/79. The decision was made to continue with all the data available to see if it gave a good indication of the properties of the populations.

Also, it should be noted that the results of the most recent testing is the first data entry with older data following. Tables 4-3 and 4-4 present the analysis of variance calculations performed in subroutine ANALVR in the standard tabular format as presented in Chapter 3. There are significant differences at first glance between the CMR and CERT data. Initially, it might be supposed that the calculation of data is incorrect. Reference to Appendix F, however, verifies that the calculations for the CERT data are correct, making it comparatively safe to say that since the CMR data was calculated with the same program it's assumed accurate.

TABLE 4-3

Part No. 3072112 CERT ANALVR Results

TREATMENT	TOTAL	MEAN.	SUM SQR DIFF	STANDARD DEV
1 (POS3)	1635.90	136.32	134.92	12.63
2 (POS4)	1636.00	136.33	125.31	11.39
3 (POS5)	1627.20	135.60	195.49	16.96
4 (POS7)	1638.90	136.57	54.72	4.97

HIGH STD.DEV. = 16.96 TOTAL ALL TREAT. STD. DEVS. =45.96

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	6.406	2.135	.186
ERROR	44.	504.469	11.465	
TOTAL	47.	510.875		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3677 K = 12

NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 4
ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	6.406	2.135	.695
CAST./FORG. NO.	11.	403.055	36.641	11.923
ERROR	33.	101.414	3.073	
TOTAL	47.	510.875		

NOTE: BOTH TWO- AND ONE-WAY ANOVA INFORMATION PROVIDED TO SHOW SYSTEM CAPABILITY. ONE-WAY ANOVA SHOULD ONLY BE USED IF IT IS KNOWN THAT BLOCKING EFFECT (CAST./FORG. NO.) EFFECT IS NEGLIGIBLE.

TABLE 4-4

Part No. 3072112 CMR ANALVR Results

TREATMENT	TOTAL	MEAN.	SUM SQR DIFF	STANDARD DEV
1 (POS3)	1884.03	134.57	95.30	7.33
2 (POS4)	1905.10	136.08	67.00	5.15
3 (POS5)	1868.60	133.47	85.59	6.58

HIGH STD.DEV. = 7.33 TOTAL ALL TREAT. STD. DEVS. =19.07

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	47.969	23.984	3.773
ERROR	39.	247.906	6.357	
TOTAL	41.	295.875		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3844 K = 14
NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 3
ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
2) ALL BLOCK MEANS ARE EQUAL

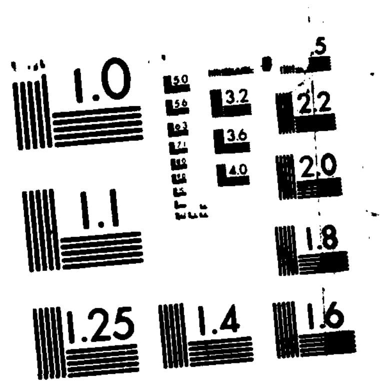
ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	47.969	23.984	10.786
CAST./FORG. NO.	13.	190.094	14.623	6.576
ERROR	26.	57.813	2.224	
TOTAL	41.	295.875		

NOTE: BOTH TWO- AND ONE-WAY ANOVA INFORMATION PROVIDED TO SHOW SYSTEM CAPABILITY. ONE-WAY ANOVA SHOULD ONLY BE USED IF IT IS KNOWN THAT BLOCKING (CAST./FORG. NO.) EFFECT IS NEGLIGIBLE.

AD-A166 418 AN APPLICATION OF QUALITY CONTROL THEORY TO VENDOR-SUPPLIED PARTS AT AN A..(U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH D E GELLENBECK AUG 85 2/3

UNCLASSIFIED AFIT/CI/NR-86-13T F/G 5/1 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

Beginning with the one-way ANOVA results, note the degrees of freedom are different (CERT = 3 for position, 39 error, 41 total; CMR = 2 for position, 44 for error, 47 total) which yields differing critical F_o values (19:397-401). The CERT F_o (0.186) becomes significant at $\alpha > 0.25$ while the CMR F_o (3.773) is significant at α = approximately 0.05.

The Cochran's homogeneity of variances statistic "g" differs only slightly, but again there are different degrees of freedom. The "g's" and their points of significance as determined by comparison to the charted values (8:688) are:

$g_{CERT\ (n = 4,\ k = 12)} = .3677$ significant at $\alpha > .05$

$g_{CMR\ (n = 3,\ k = 14)} = .3844$ significant at $\alpha \cong .04$

($\alpha = .05$, $g = .35$)
($\alpha = .01$, $g = .43$)

Thus, it is safe to say that at $\alpha = .01$, the variances of measures among the different sample pieces are the same.

The two-way analysis of variance in the case of the CERT data, verifies what had been determined in the one-way analysis of variance; the blocking (different test forgings/castings) is responsible for most of the variability, something that was suspected at the outset. The CERT two-way results are:

$F_{Tr(3.33)} = .695$ significant at $\alpha > 0.25$

$F_{Bl(11.33)} = 11.923$ significant at $\alpha < 0.01$.

The CMR two-way ANOVA, however, displays different information from the one-way:

$$F_{Tr(2.26)} = 10.786 \text{ significant at } \alpha > 0.25$$

$$F_{BL(13.26)} = 6.576 \text{ significant at } \alpha > 0.25$$

leading to rejection of both null hypothesis.

These may indicate significant differences between the vendor and AiResearch testing, data inconsistencies, "out-of-control" situations, or bad product. Quality control charts may help to clarify this situation.

Before presenting the control charts, it's appropriate to discuss which provides more information, the control charts or the analysis of variance. Basically, they both can provide the same information, but in different ways. The analysis of variance tests for variation between populations (treatments) for selected levels of confidence $(1-\alpha)$ by using extensive and somewhat complicated mathematical calculations that employ the sample standard deviation as an estimate of variance. Quality control charts also test variation between populations, but this is accomplished by utilizing simpler calculations that employ range (in the simplest case), sample standard deviation, etc., as estimates of variance and in most cases using set values of $(1-\alpha)$,

(i.e. the three-sigma (3σ) or 99.73% $1-\alpha$) confidence levels can be investigated by recalculating the control limits with values other than three as mentioned in Chapter 3. The advantage of control charts is that they provide a picture of the analysis that makes decision-making much easier for the user who is not familiar with the statistical background and/or manipulation required.[24]

A look at the control charts for the CERT and CMR test data for part number 3072112 should give a visual indication of what the one-way and two-way ANOVA results were designating. Figures 4-1 and 4-2 are the results of plotting the CERT and CMR data respectively. The "3-SIGMA X-BAR CHART" for the CERT data shows that while all the results were above the minimum specification level (the vertical line of "m"'s), they did not stay within the 3 control limits (the vertical lines of "l's") and the process appears out of control. The two-way ANOVA, it may be recalled, indicated considerable variation between the sample pieces (blocking), thus the two methods as proposed above do indeed provide the same information, though in different ways. The ranges on the "3-SIGMA R CHART" stayed well within the control limits, however, indicating the range of values within each test sample was relatively consistent as indicated by Cochran's test.

---

[24]See Duncan (9:618-19) for an in-depth discussion of this.

FIGURE 4-1:

Part No. 3072112 CERT Control Charts
(Sheet 1 of 3)

3 SIGMA-
RANGE CHART

LCL= .0000
CENTER= 3.6333
UCL= 8.2940

Scale: .000 — 2.761 — 5.523 — 8.284

SERIAL NUMBER	
2237	1.600
2164	5.100
395	4.300
2382	3.100
404	1.700
2374	3.900
83015	5.700
83345	2.000
88800	2.400
3040	4.600
3046	5.100
3010	4.100

3 SIGMA-
X-BAR CHART

LCL= 133.5560
CENTER= 136.2083
UCL= 138.8607

Scale: 130.000 — 134.058 — 138.117 — 142.175

SERIAL NUMBER	
2237	133.000
2164	134.975
395	134.825
2382	139.000
404	136.475
2374	139.675
83015	134.525
83345	139.600
88800	135.550
3040	132.950
3046	132.950
3010	142.175

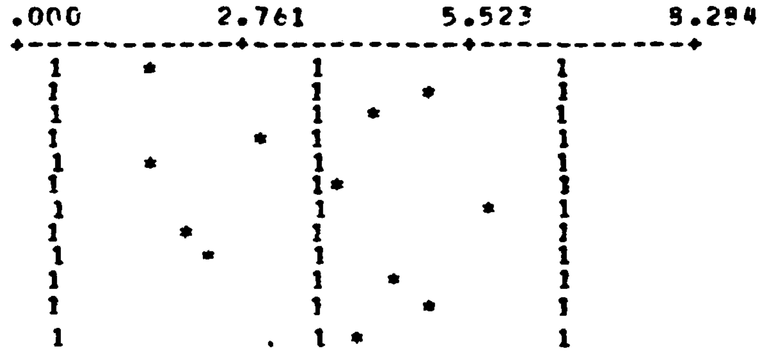
NOTE: THE MOST RECENT DATA IS DISPLAYED AT TOP OF CHARTS.

FIGURE 4-1:

Part No. 3072112 CERT Control Charts
(Sheet 2 of 3)

2 SIGMA-
RANGE CHART

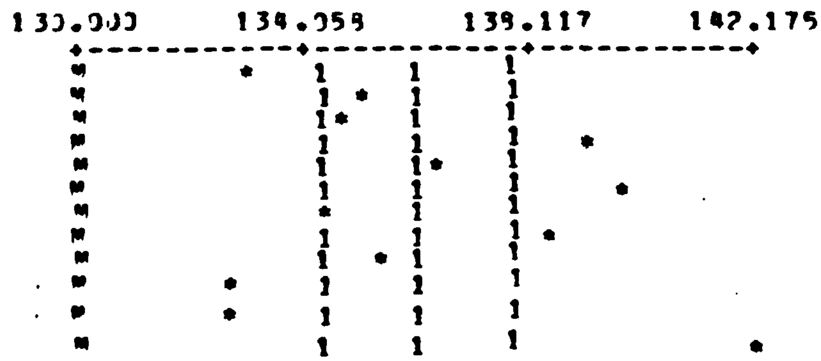
LCL= .5291
CENTER= 3.6333
UCL= 6.7319



SERIAL NUMBER	
2237	1.600
2164	5.100
395	4.300
2382	3.100
404	1.700
2374	3.900
83015	5.700
83345	2.000
88800	2.400
3040	4.600
3046	5.100
3010	4.100

2 SIGMA-
X-BAR CHART

LCL= 134.4401
CENTER= 136.2083
UCL= 137.9765



SERIAL NUMBER	
2237	133.000
2164	134.975
395	134.825
2382	139.000
404	136.475
2374	139.675
83015	134.525
83345	138.600
88800	135.550
3040	132.950
3046	132.950
3010	142.175

NOTE: THE MOST RECENT DATA IS AT THE TOP OF THE CHARTS.

FIGURE 4-1:

Part No. 3072112 CERT Control Charts (Sheet 3 of 3)

```
                                   1 SIGMA-
                                  RANGE CHART

SERIAL                LCL=     2.0512
NUMBER                             CENTER=     3.6333
                                          UCL=     5.1799

                    .000      2.761       5.523       8.284
                    +-----------+-----------+-----------+
  2237   1.600             * 1      1     1
  2164   5.100               1      1    *1
   395   4.300               1      1  *  1
  2382   3.100               1   *  1     1
   404   1.700             * 1      1     1
  2374   3.900               1      1*    1
 83015   5.700               1      1     1  *
 83345   2.000               *      1     1
 88800   2.400               1*     1     1
  3040   4.600               1      1   * 1
  3046   5.100               1      1    *1
  3010   4.100               1      1 *   1
```

```
                                   1 SIGMA-
                                  X-BAR CHART

SERIAL                LCL=  135.3242
NUMBER                             CENTER=  136.2083
                                          UCL=  137.0924

                  133.000    136.059     139.117     142.175
                    +-----------+-----------+-----------+
  2237  133.000     *         *     1 1 1
  2164  134.975     *              *1 1 1
   395  134.925     *             * 1 1 1
  2382  139.000     *               1 1 1      *
   404  136.475     *               1 1*1
  2374  139.675     *               1 1 1        *
 83015  134.525     *            *  1 1 1
 83345  138.600     *               1 1 1    *
 88800  135.550     *               * 1 1
  3040  132.950     *       *       1 1 1
  3046  132.950     *       *       1 1 1
  3010  142.175     *               1 1 1               *
```

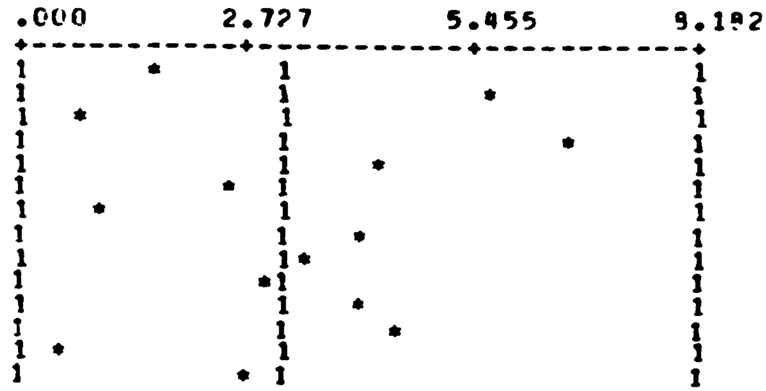
NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-2:

Part No. 3072112 CMR Control Charts
(Sheet 1 of 3)

3 SIGMA-
RANGE CHART

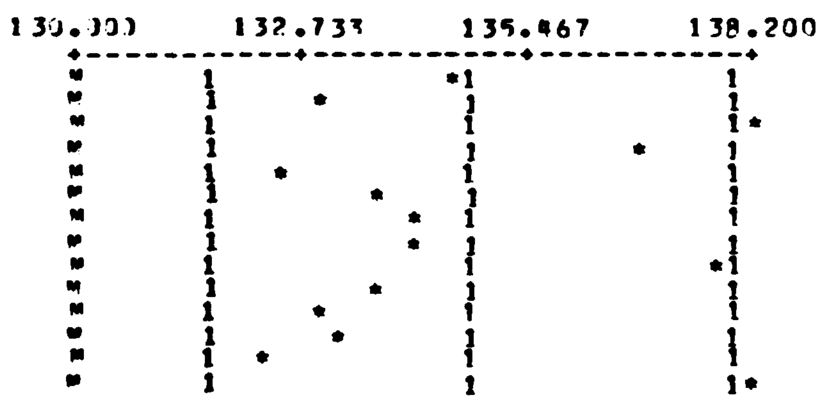
LCL= .0000
CENTER= 3.1936
UCL= 9.1919



SERIAL NUMBER	
2164	1.500
395	5.600
2382	.600
2361	6.500
3004	4.370
3443	2.600
1011	1.000
1048	4.200
800	3.400
3337	3.000
3368	4.100
3040	4.600
3046	.400
3010	2.700

3 SIGMA-
X-BAR CHART

LCL= 131.4606
CENTER= 134.7079
UCL= 137.9551



SERIAL NUMBER	
2164	134.667
395	132.933
2382	139.700
2361	136.767
3004	132.543
3443	133.667
1011	134.200
1048	134.100
800	137.933
3337	133.733
3368	133.033
3040	133.200
3046	132.333
3010	139.200

NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-2:

Part No. 3072112 CMR Control Charts
(Sheet 2 of 3)

2 SIGMA-
RANGE CHART

LCL= .0000
CENTER= 3.1936
UCL= 6.5052

Scale: .000 — 2.727 — 5.455 — 8.182

SERIAL NUMBER	
2164	1.500
395	5.600
2382	.600
2361	6.500
3004	4.370
3443	2.600
1011	1.000
1048	4.200
800	3.400
3337	3.000
3368	4.100
3040	4.600
3046	.400
3010	2.700

2 SIGMA-
X-BAR CHART

LCL= 132.5430
CENTER= 134.7079
UCL= 136.8727

Scale: 130.000 — 132.733 — 135.467 — 138.200

SERIAL NUMBER	
2164	134.667
395	132.933
2382	139.700
2361	136.767
3004	132.543
3443	133.667
1011	134.200
1048	134.100
800	137.933
3337	133.733
3368	133.033
3040	133.200
3046	132.333
3010	139.200

NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

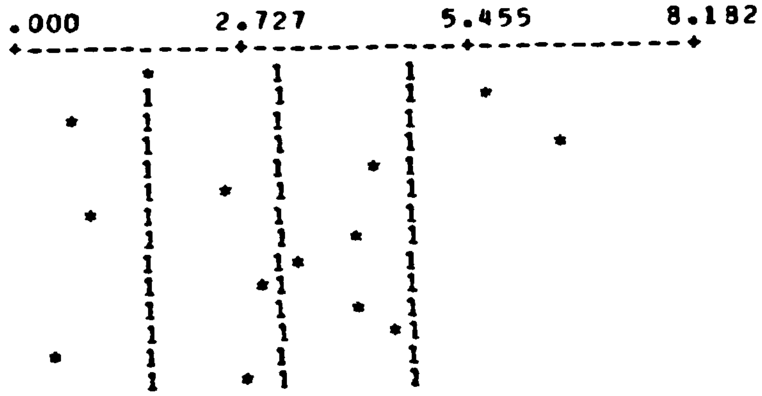
FIGURE 4-2:

Part No. 3072112 CMR Control Charts
(Sheet 3 of 3)

1 SIGMA-
RANGE CHART

LCL= 1.5070
CENTER= 3.1836
UCL= 4.8287

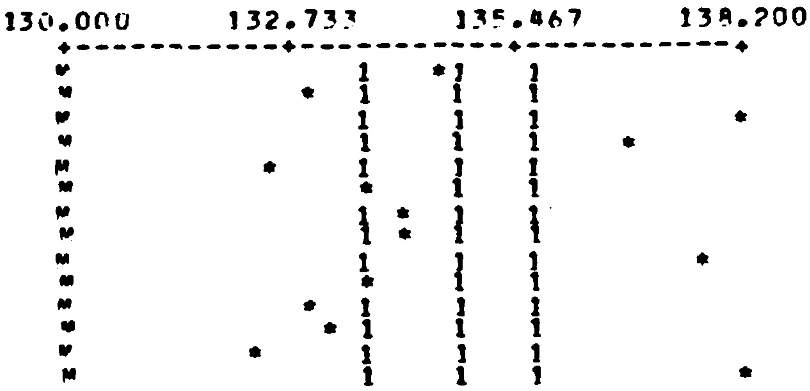
SERIAL NUMBER	
2164	1.500
395	5.600
2382	.600
2361	6.500
3004	4.370
3443	2.600
1011	1.000
1048	4.200
800	3.400
3337	3.000
3368	4.100
3040	4.600
3046	.400
3010	2.700



1 SIGMA-
X-BAR CHART

LCL= 133.6254
CENTER= 134.7079
UCL= 135.7903

SERIAL NUMBER	
2164	134.667
395	132.933
2382	138.700
2361	136.767
3004	132.543
3443	133.667
1011	134.200
1048	134.100
800	137.833
3337	133.733
3368	133.033
3040	133.200
3046	132.333
3010	138.200



NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

The CMR charts for part number 3072112 show somewhat better control than those for the CERT data, but there are still points outside the three-sigma limits. The range charts show good control. While the result of the two-way ANOVA can be seen in the charts it is not as clear as in the case of the CERT data. Plots of the individual data points, however, may aid in this.

Figures 4-3 and 4-4 depict these plots. Even a quick glance shows what the control charts had depicted in detail. For the CERT data, there is a wide dispersion of values, but the range of each piece doesn't appear excessive; the situations the control charts showed for the CMR data, the true worth of the plot is seen with one of the test results falling below minimum specifications. The dispersion of values and the differing of values that the range chart and two-way analysis of variance showed, and Cochran's "g" confirmed, can be seen.

To compare the two sets of data is difficult, if not impossible with the out-of-control situations observed. Since the data for the matched pairs is dependent, however, it may be beneficial to at least look at the results of the T^* testing. Table 4-5 presents the data and results for the paired test data means (the mean values of yield tests on respective halves of each tested casting/forging) and reference to the tables of t^* values (18:488) for 9 degrees of freedom leads to the following: $t^* = 2.0811$

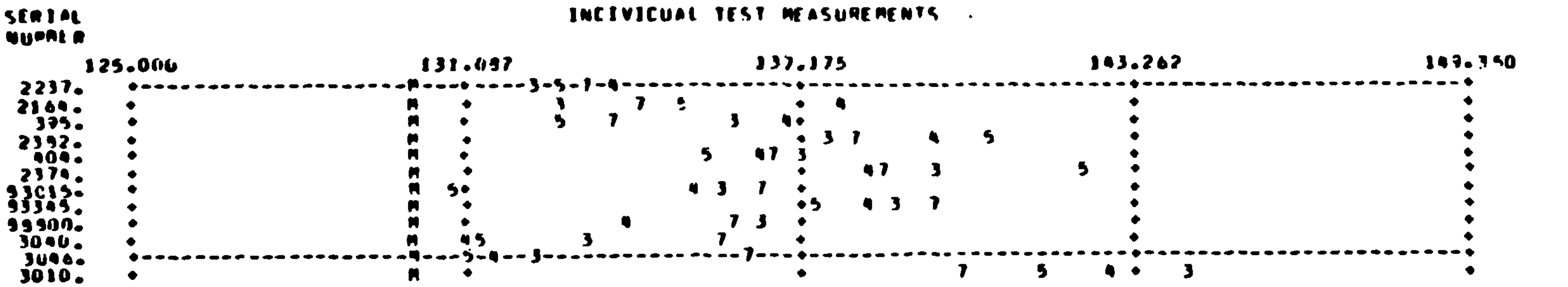
**ROOM TEMP.TENSILE TESTS-YIELD LAT.RAD.(1/77 TO 5/79) CERT DATA

VALUE PLOT:

(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--TFE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING



NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.

2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

3) MOST RECENT DATA IS AT TOP OF PLOT.

FIGURE 4-3

Part No. 3072112 CERT Individual Data Plot

**ROOM TEMP. TENSILE TESTS-YIELD   LAC-PACIFIC(1/77 TO 10/79)CMR DATA

VALUE PLOT:

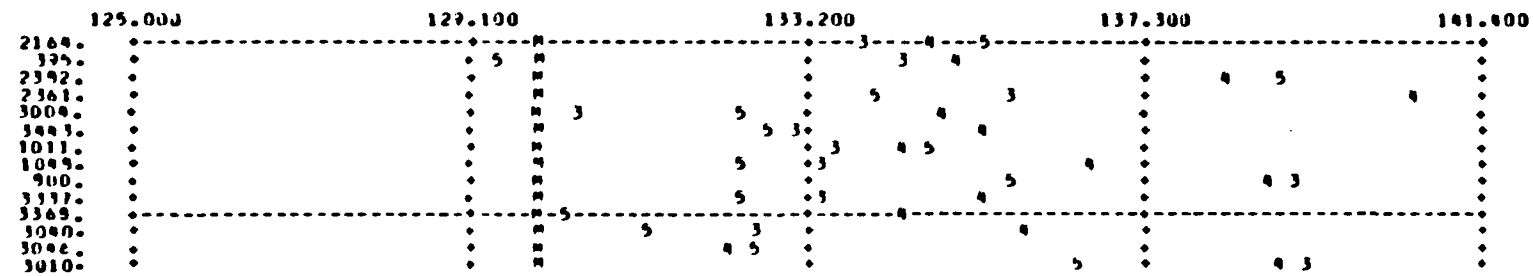
(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--TFE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING

SERIAL NUMBER

INDIVIDUAL TEST MEASUREMENTS



NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.
2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

3) MOST RECENT DATA IS AT TOP OF PLOT.

FIGURE 4-4

Part No. 3072112 CMR Individual Data Plot

TABLE 4-5

Part No. 3072112 CERT vs. CMR Paired T-test

DETERMINATION OF A CIFFFRFNCE IN TESTING FOR
PART NUMBER: *3072112 LACISH PACIFIC TESTING VS. ARC CO. TESTING
CATA FROM 1/77 TO 5/79 (YIELC CATA)

NOTE: MOST RECENT DATA IS AT TOP OF TABLE.

SER.NO.	CERT CATA	CMR CATA	CIFFERENCE	CIFF.SORC
2164	134.975	134.667	.3080	.0949
395	134.825	132.933	1.8920	3.5797
2382	139.000	138.700	.3000	.0900
82374	139.675	136.767	2.9080	8.4565
83015	134.525	132.548	1.9770	3.9085
83345	138.600	133.667	4.9330	24.3345
88800	135.550	137.833	-2.2830	5.2121
3040	132.850	133.200	-.3500	.1225
3046	132.850	132.333	.5170	.2673
3010	142.175	138.200	3.9750	15.8006
TOTAL			14.1770	61.8665

AVERAGE CIFFERENCE = 1.4177 CEG. OF FREECOM = 9
SAMPLE VARIANCE = 4.641 SAMPLE STANCARC CEV. = 2.15

THE "T*" STATISTIC FOR TESTING THE CIFFERENCE IN THE TWO TESTING MEANS = 2.0911
NULL HYPOTH.: U1-U2 = CMU
ALT. HYPOTH.: U1-U2.NE.CMU
ASSUMPTION: THF CISTRIBUTION UNCERLYING THE CIFFERENCES IS NORMAL.

Critical value: at $\alpha = .05$ $\quad |t^*| > t_{.05,9} = 1.833$

reject $H_o: \mu_{CERT} - \mu_{CMR} = 0$

$H_1: \mu_{CERT} - \mu_{CMR} = 0$

at $\alpha = .01$ $\quad |t^*| < t_{.01,9} = 2.821$

accept $H_o: \mu_{CERT} - \mu_{CMR} = 0$

and the means can be considered equal, something that was intuitively obvious, but now can be statistically proven. The fact that H_0 must be rejected at $\alpha = .05$ would caution the user to investigate factors that might cause the means to be unequal such as differences in testing technique.

As a point of interest, it may be noted that the values of the difference between each pair of data are provided. This could be used to test data from two different vendors manufacturing the same part through use of the Wilcoxon two sample test in the event the distributions underlying the values is decidedly normal (33 :254-258). Such data was not available for this study and, hence no examples of such a test are provided.

Part Number 3072316--
Forged Turbine Disk of Waspaloy, Condition B

Reviewing the control charts for test results of part number 3072316 illustrates the use of the developed programs in analyzing individual (one sample/test forging) measurement data. Tables 4-6 and 4-7 present the individual measurement data for the ultimate stress portion of the room temperature Tensile test for the CERT and CMR data while

TABLE 4-6

Part No. 3072316 CERT Individual Measurements Data

SERIAL #		INPUT DATA BY POSITION	
275	197.10	1209	191.40
230	190.40	1300	196.40
267	192.00	1301	196.40
223	197.50	960	191.00
152	195.90	909	190.60
155	194.00	949	195.60
4096	192.90	341	196.80
4069	199.60	2505	192.40
4025	191.50	2543	196.40
4019	190.40	1962	195.20
2607	191.60	1967	192.80
2609	193.60	1165	195.60
2575	199.60	390	191.10
2673	194.90	9919	193.20
1226	194.50	570	192.40
1202	199.40		

THE MEAN = 190.67 SUM OF SQUARES =1127595.55

STAND DEV = 4.37 SUM = 5910.80

TABLE 4-8

Part No. 3072316 CERT Grouped Data

1	197.10	190.40	192.00
2	197.50	195.90	194.00
3	192.90	199.60	191.50
4	190.40	191.60	193.60
5	199.60	194.90	194.50
6	199.40	191.40	196.40
7	196.40	191.00	190.00
8	195.00	196.80	192.40
9	196.40	195.20	192.80
10	195.60	191.10	193.20

NOTE: MOST RECENT DATA IS AT TOP OF TABLES.

TABLE 4-7

Part No. 3072316 CMR Individual Measurements Data

FORMAT(I5,F10.2)

SERIAL #		INPUT DATA BY POSITION	
267	191.90	2509	194.30
223	192.30	2543	192.70
152	191.40	1962	190.60
155	191.50	1967	191.30
2607	195.90	1165	197.50
2609	192.70	390	194.90
2575	195.10	9392	195.20
2673	199.60	9919	193.10
1226	200.00	570	199.60
1202	189.50	2000	191.50
1209	197.40	1950	193.90
960	197.60		
909	196.50		
948	190.00		
9711	195.90		
391	195.80		

THE MEAN = 193.29

STAND DEV = 3.69

SUM = 5219.70

SUM OF SQUARES =1009049.79

TABLE 4-9

Part No. 3072316
CMR Grouped Data

1	191.90	[illegible]	[illegible]
2	191.50	195.90	[illegible]
3	195.10	199.60	[illegible]
4	199.90	197.40	[illegible]
5	196.50	190.00	[illegible]
6	195.50	194.30	[illegible]
7	190.60	191.30	[illegible]
8	190.90	195.20	[illegible]
9	192.60	191.50	[illegible]

NOTE: MOST RECENT DATA IS AT TOP OF TABLES.

tables 4-8 and 4-9 present the grouped data. The values were grouped in three's by simply taking the three most recent values (top three on individual data table), then the next three, etc. A decision was made to bypass the ANOVA calculations since, with the grouped data, it wasn't necessary.

Figures 4-5 and 4-6 present the grouped "3-SIGMA" and "2-SIGMA X-BAR" and "RANGE" charts for the CERT and CMR data. Looking at the CERT $\bar{X}$ charts shows some interesting behavior in the grouped average; the trend toward lower average ultimate stress values over time is of particular interest. The average of the latest three tests (group 1) has fallen close to the lower three-sigma limit and is in fact below the two-sigma limit. The range charts show things "in-control". The CMR control charts don't really depict this trend. The charts of individual measurements with the grouped X-bar control limits (3σ), figures 4-7 and 4-8, shows how the samples performed over time. Note the trend indicated on the grouped CERT X-bar chart is quite obvious on the CERT individual chart while the CMR individual chart shows little or no trend.

The reasons for such a discrepancy are difficult to pinpoint, but may be due to a degradation in the vendor's test equipment, a process trend in the manufacturing, or problems in AiResearch test procedures.

FIGURE 4-5:

Part No. 3072316 CERT Grouped Control Charts
(Sheet 1 of 2)

```
                                         3 SIGMA-
                                       RANGE CHART

SERIAL               LCL=      .0000
(GROUP)                            CENTER=    6.9300
NUMBER                                  UCL=    17.5531

                     .000        5.851       11.702       17.553
                     +-----------+-----------+-----------+
   1      6.700      1            *                      1
   2      9.100      1            1    *                 1
   3      9.500      1            1    *                 1
   4      5.000      1        *   1                      1
   5      5.900      1          * 1                      1
   6     12.400      1            1           *          1
   7      8.000      1            1  *                   1
   8      4.000      1      *     1                      1
   9      4.900      1        *   1                      1
  10      2.900      1    *       1                      1




                                         3 SIGMA-
                                       X-BAR CHART

SERIAL               LCL=  181.6901
(GROUP)                            CENTER=  188.6567
NUMBER                                  UCL=  195.6233

                   175.000     181.874     188.749     195.623
                     +-----------+-----------+-----------+
   1    183.167      M           1 *         1           1
   2    184.633      M           1    *      1           1
   3    185.933      M           1      *    1           1
   4    190.567      M           1           1  *        1
   5    186.933      M           1        *  1           1
   6    191.333      M           1           1    *      1
   7    189.200      M           1           1*          1
   8    189.900      M           1           1 *         1
   9    193.567      M           1           1       *   1
  10    191.533      M           1           1    *      1
```

NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-5:

Part No. 3072316 CERT Grouped Control Charts
(Sheet 2 of 2)

```
                                      2 SIGMA-
                                    RANGE CHART

SERIAL
(GROUP)              LCL=      .0000
NUMBER                              CENTER=    6.8300
                                                  UCL=    13.9562

                     .000       5.851       11.702      17.553
                     +-----------+-----------+-----------+
   1     6.700       I           *              I
   2     9.100       I           I    *         I
   3     9.500       I           I    *         I
   4     5.001       I        *  I              I
   5     5.900       I          *I              I
   6    12.400       I           I          *   I
   7     8.000       I           I *            I
   8     4.000       I      *    I              I
   9     4.900       I        *  I              I
  10     2.800       I    *      I              I
```

```
                                      2 SIGMA-
                                    X-BAR CHART

SERIAL
(GROUP)              LCL=  184.0123
NUMBER                              CENTER=  188.6567
                                                  UCL=  193.3011

                  175.003     181.874     188.749     195.623
                     +-----------+-----------+-----------+
   1   193.167       *         * I       I      I
   2   184.633       *           I*      I      I
   3   185.333       *           I  *    I      I
   4   190.567       *           I       I  *   I
   5   186.933       *           I    *  I      I
   6   191.333       *           I       I    * I
   7   189.230       *           I       I*     I
   8   189.900       *           I       I *    I
   9   193.567       *           I       I      *
  10   191.533       *           I       I    * I
```

NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-6:

Part No. 3072316 CMR Grouped Control Charts
(Sheet 1 of 2)

```
                                   3 SIGMA-
                                  RANGE CHART

SERIAL                LCL=      .0000
(GROUP)                            CENTER=     6.2444
NUMBER                                   UCL=    16.0482

                      .000       5.349       10.699      16.049
                       +-----------+-----------+-----------+
  1       .900         I *         I                       I
  2      1.200         I  *        I                       I
  3      9.600         I           I    *                  I
  4      4.500         I       *   I                       I
  5     10.000         I           I      *                I
  6      5.700         I          *I                       I
  7      7.900         I           I  *                    I
  8     10.200         I           I       *               I
  9      7.300         I           I *                     I
```

```
                                   3 SIGMA-
                                  X-BAR CHART

SERIAL                LCL=  186.0962
(GROUP)                            CENTER=  192.4555
NUMBER                                   UCL=  198.8249

                    175.000     182.942     190.883     198.825
                       +-----------+-----------+-----------+
  1    191.867         *               I      *I           I
  2    192.167         *               I       *           I
  3    194.700         *               I       I   *       I
  4    189.033         *               I   *   I           I
  5    190.200         *               I     * I           I
  6    190.900         *               I      *I           I
  7    194.300         *               I       I  *        I
  8    193.500         *               I       I *         I
  9    195.533         *               I       I    *      I
```

NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-6:

Part No. 3072316 CMR Grouped Control Charts (Sheet 2 of 2)

```
                                               2 SIGMA-
                                              RANGE CHART

SERIAL                   LCL=       .0000
(GROUP)                                    CENTER=     6.2444
NUMBER                                              UCL=    12.7597

                         .000        5.349       10.699      16.049
                         +-----------+-----------+-----------+
   1         .900        I *         I              I
   2        1.200        I  *        I              I
   3        9.600        I           I    *         I
   4        4.500        I        *  I              I
   5       10.000        I           I       *      I
   6        5.700        I          *I              I
   7        7.900        I           I  *           I
   8       10.200        I           I       *      I
   9        7.300        I           I *            I
```

```
                                               2 SIGMA-
                                              X-BAR CHART

SERIAL                   LCL=  188.2093
(GROUP)                                    CENTER=  192.4555
NUMBER                                              UCL=   196.7018

                      175.000     182.942     190.883     198.825
                         +-----------+-----------+-----------+
   1       191.967       *                 I    *I     I
   2       192.167       *                 I     *     I
   3       194.700       *                 I     I   * I
   4       189.033       *                 I*    I     I
   5       190.200       *                 I  *  I     I
   6       190.900       *                 I   * I     I
   7       194.300       *                 I     I  *  I
   8       193.500       *                 I     I *   I
   9       195.533       *                 I     I   * I
```

NOTE: THE MOST RECENT DATA IS DISPLAYED AT THE TOP OF CHARTS.

FIGURE 4-7

Part No. 3072316 CERT Individual Measurements Control Chart

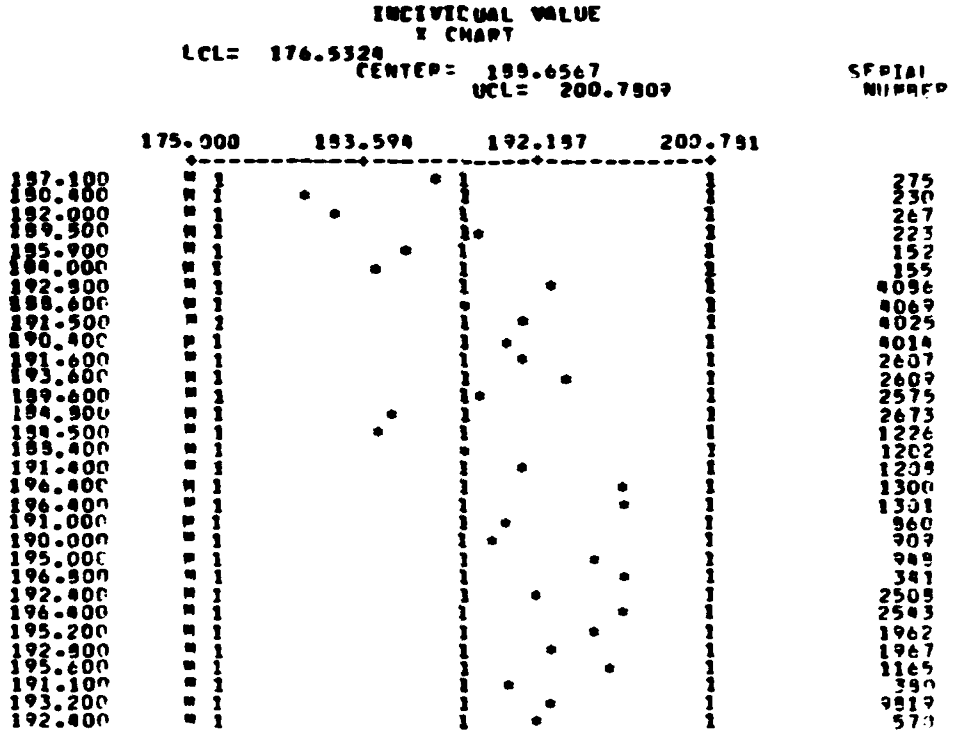
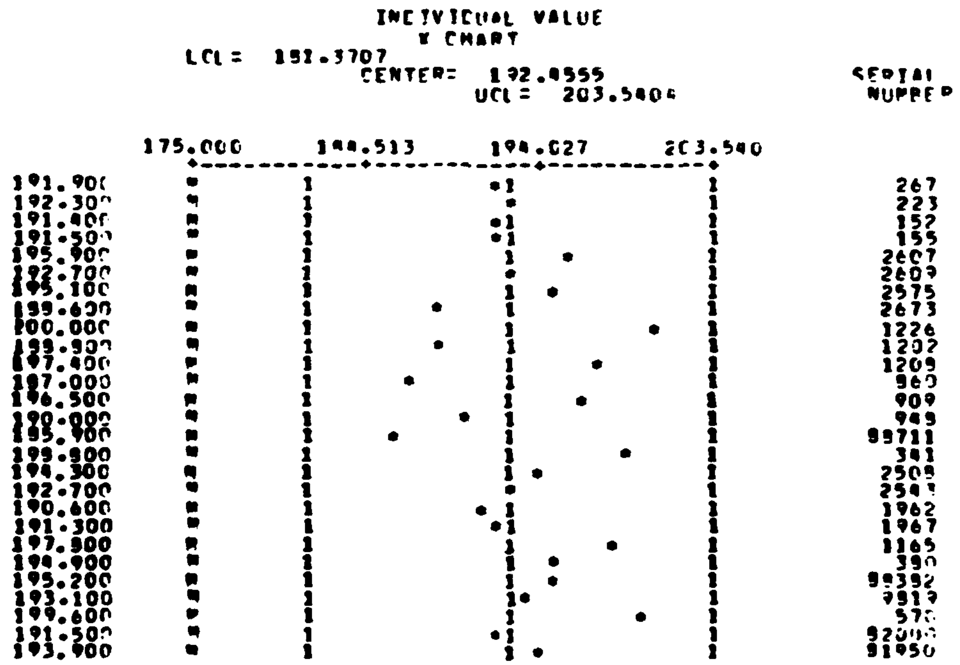


FIGURE 4-8

Part No. 3072316 CMR Individual Measurements Control Chart



NOTE: THE MOST RECENT DATA IS DISPLAYED AT TOP OF FIGURES.

The test for equality of means of the paired observations (again, the respective halves of the tested forgings) is presented in table 4-10. Testing at α = .01 and .05 shows

$t^* = -2.7153$ with 22 degrees of freedom

critical value at $\alpha = .05$ $|t^*| > t_{.05,22} = 1.717$

reject $H_o: \mu_{CERT} - \mu_{CMR} = \emptyset$

at $\alpha = .01$ $|t^*| > t_{.01,22} = 2.508$

reject $H_o: \mu_{CERT} - \mu_{CMR} = \emptyset$

and as stated previously, the user would have to investigate to determine the cause for the inequality since it would be expected that they would be statistically equivalent.

In both cases (both selected parts) there was a limited amount of data available, making it difficult to get a good estimate of the statistics of the populations. Most sources recommended at least 25 samples of good data to give such an estimate (6:112), but this amount was not available. Also, the condition of test results reports (CERT's and CMR's) made it difficult to obtain any more data. The rough data sheets (see Appendix B) summarize the data the author was able to glean from extensive research of the records. Additionally, it was particularly difficult to pick values from the CMR's due to poor organization and lack of consistency in the original AiResearch and vendor data.

The programs developed in this study were verified by manually analyzing the data. An example for part No.

TABLE 4-10

Part No. 3072316 CERT vs. CMR Paired T-test

SER.NO.	CERT DATA	CMR DATA	DIFFERENCE	DIFF.SQRD
267	182.000	191.900	-9.9000	98.0100
223	189.500	192.300	-2.8000	7.8400
152	185.900	191.400	-5.5000	30.2500
155	184.000	191.500	-7.5000	56.2500
2637	191.600	195.900	-4.3000	18.4900
2609	193.600	192.700	.9000	.8100
2575	189.600	195.100	-5.5000	30.2500
2673	184.800	188.600	-3.8000	14.4400
1226	184.500	200.000	-15.5000	240.2500
1202	188.400	188.800	-.4000	.1600
1219	191.400	197.400	-6.0000	36.0000
960	191.000	187.000	4.0000	16.0000
909	190.000	196.500	-6.5000	42.2500
948	195.000	190.000	5.0000	25.0000
381	196.800	198.800	-2.0000	4.0000
2508	192.400	194.300	-1.9000	3.6100
2543	196.400	192.700	3.7000	13.6900
1962	195.200	190.600	4.6000	21.1600
1967	192.800	191.300	1.5000	2.2500
1165	195.600	197.800	-2.2000	4.8400
39[illegible]	191.100	194.900	-3.8000	14.4400
9519	193.200	193.100	.1000	.0100
570	192.400	199.600	-7.2000	51.8400
TOTAL			-65.0000	731.8399

AVERAGE DIFFERENCE = -2.8261   DEG. OF FREEDOM = 22

SAMPLE VARIANCE = 24.916   SAMPLE STANDARD DEV. = 4.99

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -2.7153
NULL HYPOTH.: U1-U2 = CMU
ALT. HYPOTH.: U1-U2.NE.CMU
ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

NOTE: MOST RECENT DATA IS AT TOP OF TABLE.

3072112 CERT yield data analysis of variance (ANOVA) is presented in Appendix F, along with analysis of the three treatment means of the CMR yield data using Duncan's test.

The results obtained by analyzing the two test cases provided a means of evaluating, in particular, the capabilities and applicability of the two programs developed and, in general, the quality control system designed for AiResearch forging/casting testing.

Admittedly, the data available to evaluate the quality control system developed in Chapter 3 failed to illustrate how the computer outputs/analyses produced can aid management in making decisions to reduce cost of inspection, change specifications, reduce testing frequency of volume, etc. Three examples have been developed to aid in understanding application of the system.

Example 1 (Figure 4-9) illustrates a "borderline" case where a trend in the "X-BAR" chart toward the lower control limit and the specified minimum value, in both the 2- and 3-sigma cases, may indicate impending trouble. The chronologically latest measurements are presented at the top of the charts, i.e. the most recent data is on top.

Assuming the process, in the past, was "under control," such a trend may indicate that a mold or die is deteriorating, faulty materials are being supplied to the vendor, or that the vendor is adjusting the process to bring the average value closer to the minimum specified. Such

FIGURE 4-9:

Control Charts for Example 1
(Sheet 1 of 2)

```
                                        3 SIGMA-
                                      RANGE CHART

ITEM                  LCL=      .0000
NUMBER                                 CENTER=   10.6800
                                             UCL=    27.4476

                      .000        9.149       18.298       27.448
                      +-----------+-----------+-----------+
  1       7.400       I         *  I                       I
  2       9.500       I           *I                       I
  3      16.700       I            I         *             I
  4       4.500       I     *      I                       I
  5      11.700       I            I*                      I
  6      16.800       I            I         *             I
  7      12.300       I            I *                     I
  8       1.400       I *          I                       I
  9       2.900       I  *         I                       I
 10      23.600       I            I                  *    I
```

```
                                        3 SIGMA-
                                      X-BAR CHART

ITEM                  LCL=   126.2597
NUMBER                                 CENTER=   137.1533
                                             UCL=   148.0469

                   120.000      129.349      138.698      148.047
                      +-----------+-----------+-----------+
  1     129.767       I      I  *          I               I
  2     130.400       I      I   *         I               I
  3     133.600       I      I       *     I               I
  4     138.200       I      I             I*              I
  5     137.533       I      I             I*              I
  6     138.833       I      I             I *             I
  7     135.867       I      I           * I               I
  8     138.767       I      I             I *             I
  9     144.900       I      I             I           *   I
 10     144.767       I      I             I           *   I
```

NOTE: THE MOST RECENT DATA IS ON TOP OF THE CHARTS
(ITEM NO. 1).

FIGURE 4-9:

Control Charts for Example 1
(Sheet 2 of 2)

```
                                                 2 SIGMA-
                                               RANGE CHART

 ITEM                        LCL=         .0000
NUMBER                                         CENTER=   10.6900
                                                             UCL=   21.8232

                             .000         9.149        18.299        27.449
                             +------------+------------+------------+
  1       7.800              I         *  I               I
  2       9.500              I          * I               I
  3      16.700              I            I       *       I
  4       4.500              I     *      I               I
  5      11.700              I            I*              I
  6      16.900              I            I       *       I
  7      12.300              I            I  *            I
  8       1.400              I *          I               I
  9       2.900              I   *        I               I
 10      23.600              I            I               I *
```

```
                                                 2 SIGMA-
                                               X-BAR CHART

 ITEM                        LCL=  129.8909
NUMBER                                         CENTER=   137.1533
                                                           UCL=  144.4157

                        120.000       129.349       138.698       148.047
                             +------------+------------+------------+
  1     128.767              I          * I         I         I
  2     130.400              I            *         I         I
  3     133.600              I            I     *   I         I
  4     139.200              I            I         I*        I
  5     137.533              I            I         I*        I
  6     139.933              I            I         I  *      I
  7     135.967              I            I       * I         I
  8     139.767              I            I         I  *      I
  9     144.900              I            I         I         I*
 10     144.767              I            I         I         I*
```

NOTE: THE MOST RECENT DATA IS ON TOP OF THE CHARTS (ITEM NO. 1).

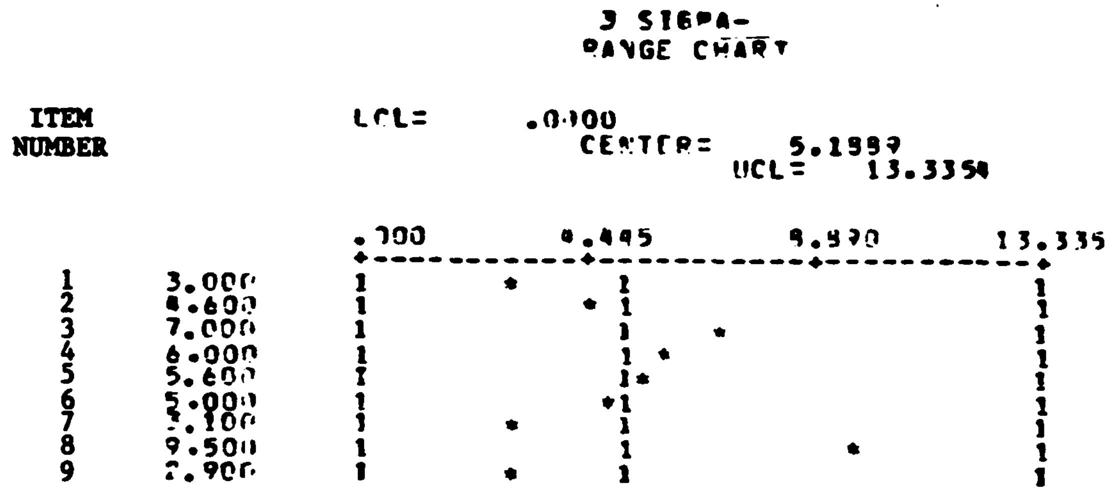
information can be used to warn the vendor of impending problems in the hope it can be quickly corrected before quality drops below the minimum specification. Complaints from customers, then, can be minimized. This can also be used as a basis for improvement of vendor/manufacturer relations; early notification of the trend allows the vendor to investigate the cause(s) before quality falls, a situation that could jeopardize a contract. Testing in this case would be continued at the same level to provide monitoring of any corrective measures taken.

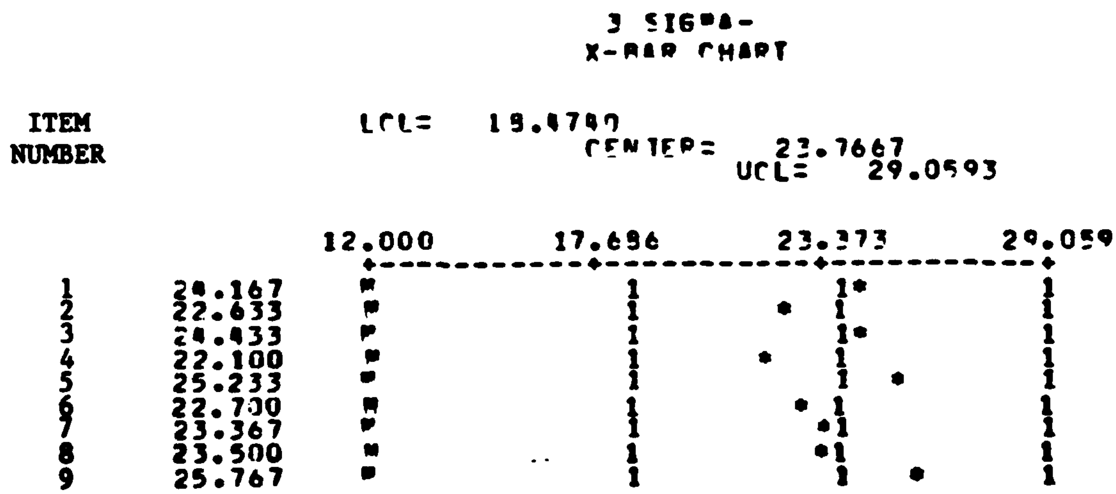
Presentation of data in control chart form can provide a concise, chronological record of performance that can be used to present a case to the appropriate persons in an organization. Such a record can also be used to provide evidence in liability cases brought against a manufacturer or vendor (7:207-9).

A process in "good control" is presented in Example 2 (Figure 4-10). The 3-sigma "X-BAR" chart shows all values clustered near the center line ($\bar{\bar{X}}$) as are most values on the 3-sigma "RANGE" chart. The 2-sigma charts confirm that there are no points even approaching the "warning limits" (2-sigma control limits) indicating quite good control. Such a chart indicates that a reduced testing frequency is a possibility, thus reducing the cost of testing. Also, the high average ($\bar{\bar{X}}$) value indicates that investigation of the minimum specification value is called for. Perhaps material

FIGURE 4-10:

Control Charts for Example 2
(Sheet 1 of 2)





NOTE: MOST RECENT DATA IS AT THE TOP OF THE CHARTS.

FIGURE 4-10:

Control Charts for Example 2
(Sheet 2 of 2)

```
                                   2 SIGMA-
                                  RANGE CHART

ITEM                   LCL=      .0000
NUMBER                              CENTER=     5.1999
                                            UCL=    10.6025

                        .000        4.445        8.890        13.335
                         +------------+------------+------------+
  1        3.000         I        *    I               I
  2        4.600         I            *I               I
  3        7.000         I             I       *       I
  4        6.000         I             I  *            I
  5        5.600         I             I*              I
  6        5.000         I            *I               I
  7        3.100         I        *    I               I
  8        9.500         I             I            *  I
  9        2.900         I        *    I               I
```

```
                                   2 SIGMA-
                                  X-BAR CHART

ITEM                   LCL=    20.2382
NUMBER                              CENTER=    23.7667
                                            UCL=    27.2951

                      12.000       17.686       23.373       29.059
                         +------------+------------+------------+
  1       24.167         *                I       I*      I
  2       22.633         *                I    *  I       I
  3       24.433         *                I       I*      I
  4       22.100         *                I   *   I       I
  5       25.233         *                I       I   *   I
  6       22.700         *                I     * I       I
  7       23.367         *                I      *I       I
  8       23.500         *                I      *I       I
  9       25.767         *                I       I    *  I
```

NOTE: MOST RECENT DATA IS AT THE TOP OF THE CHARTS.

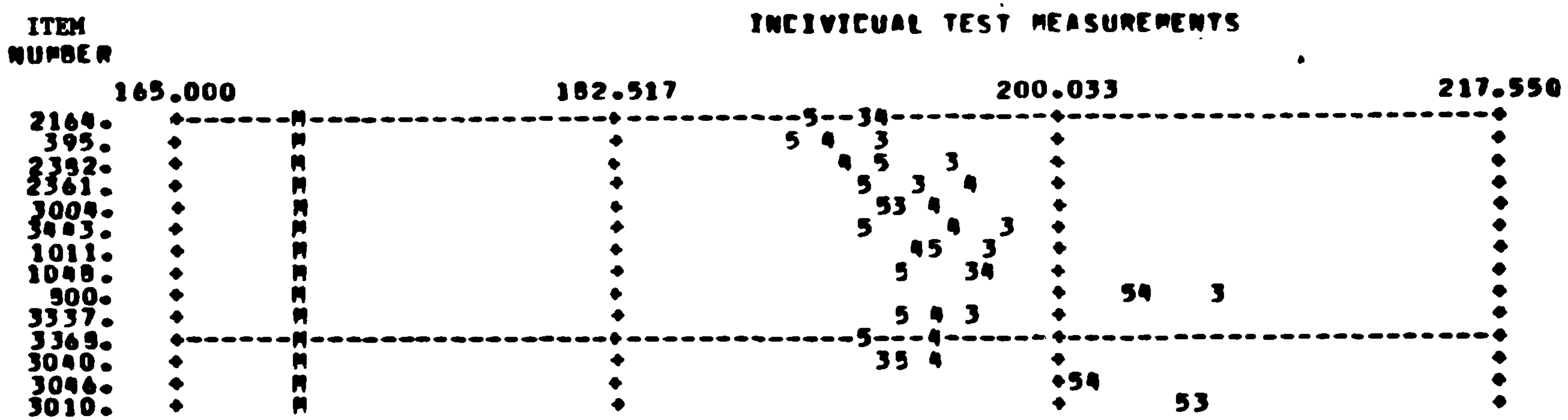
composition or processing could be changed or eliminated. If the higher value is in some way beneficial to the manufactured product, cash awards or other incentives might be given to the vendor, or a higher "vendor certification" (giving that vendor a preference over others supplying the same product) could be assigned that vendor. It may also be used to reduce inspection/testing by either vendor or manufacturer; testing of only one item per heat of material versus three, elimination of one type of test (say, %-elongation) conducted on a sample, etc.

Finally, Example 3 demonstrates how to handle the testing position problem in order to reduce testing. Table 4-10 shows the values used to obtain the plot of all the individual measurements by position (Figure 4-11). Looking at the values and averages for each position, and assuming the process is "in control," it becomes obvious that position 5 values are significantly lower than the position 3 or 4 values, and the average values of positions 3 and 4 are almost the same. The individual measurement plot provides a picture of the situation. A measure that might be taken is a reduction in testing positions, i.e., testing in only 1 or 2 positions. The author's recommendation would be to only test position 5 on a regular basis, as its average value is closer to the specification minimum. The other positions could be tested less frequently. Also, as in Example 2 above, the minimum specification value should

TABLE 4-11:

Values of Individual Measurements for Example 3

ITEM NO.	POS. 3	POS. 4	POS. 5
2164	192.10	193.30	190.20
395	192.70	191.00	189.40
2382	196.10	191.40	192.90
2361	194.50	196.20	192.10
3004	193.43	194.90	193.10
3443	198.00	195.70	192.30
1011	196.90	194.10	195.30
1048	196.50	197.50	193.90
800	206.10	203.30	202.70
3337	196.30	195.10	193.90
3368	194.90	194.90	192.00
3040	192.70	195.30	193.80
3046	200.80	201.60	200.60
3010	205.50	204.70	204.90
TOTAL	2756.53	2749.00	2727.10
AVERAGE	196.90	196.36	194.79



NOTE: 1) MISSING NUMBERS INDICATE MEASUREMENTS ALMOST EQUAL IN VALUE. CHECK CATA (ACCORCING TO ITEM NUMBER) FOR EXACT VALUES.

2) AN ASTERISK (*) INCICATES A VALUE OUT OF LIMITS.

FIGURE 4-11:

Individual Measurements Chart for Example 3

be looked at due to the difference between the average values for each position and the specification minimum. If this value is changed, changes in the overall specifications of the item might result.

"In control" control charts can be used to verify there are few (or no) assignable causes for a test result that may approach or slightly exceed a control limit. This can eliminate labor hours required to change settings, tools, etc.

While there are other possible uses of the quality control charts, they are too numerous to completely detail. Reference to the various publications listed as references to this report may indicate even more uses.

Chapter 5 presents the conclusions derived from this evalution and some recommendations for further research.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

> It is in [the] rather uneasy balance between customer desires for perfection and manufacturer's desire to minimize cost that quality control operates (31:8).

Summary and Conclusions

The quality control system proposed by this report provides a viable means of monitoring the quality of vendor product received by AiResearch and providing useful, statistically sound data for use in managerial decisions concerning vendor reliability and testing sufficiency. In this way, the cost of testing may be reduced as may the cost of the product and/or it may simply precipitate better relations with the vendor.

Likewise, the computer programs designed in support of this QC system provide quality control charts and statistical analysis of testing performed by both the vendor and AiResearch and may be utilized to analyze any typical quality control data. The programs possess both the flexibility and the efficiency to apply to any quality control analysis and can present it in a format understandable to either the statistically experienced or the inexperienced user.

The study of the quality control process at AiResearch, both preliminary to and during development of the proposed system, highlighted some shortcomings in the existing quality control program; most notably, the lack of a summary of testing information from the CERT's and CMR's and the reliance on intuitive evaluations of these results for acceptance/rejection of material. The computer files designed for the system, and use of the proposed system should alleviate both of these problems. Initially, educating the inexperienced users may require some investment in time and money, but not unreasonable amounts. It should be recovered in a very short period.

The data chosen for testing of the programs did not exhibit the properties of a process in-control, but this was not necessary. It provided better indications of the accuracy and flexibility of the programs, however, than would "canned" data that displayed "in-control" situations. It is probably typical of data that a user would encounter in the workplace. While cost considerations were not covered in depth, it's obvious that if a process was shown to be "in-control" and there was no statistical difference in the means (or a constant difference) then testing of some positions could be eliminated. Of course, this would reduce the combined $1.4 million annual testing costs (32:1) of AiResearch and the vendors and theoretically, the cost of engines. Another benefit might be the establishment of a vendor

certification process that would allow vendors of particular parts with processes "in-control" for an appropriate period of time to have their parts tested less frequently. This would also result in savings. In summary, the data used, in particular part No. 3072112, had insufficient data to accomplish this. The other sample case, while showing good control and meeting, in general, the specifications, presented a discrepancy between mean values, at least in the ultimate yield testing and trends in the testing that disqualified it also. This indicates, however, that the charting and analysis programs are capable of identifying these variations.

In gathering the data and developing the system, there were assumptions made to fit the specific situation and to provide simpler, yet statistically accurate solutions for the benefit of understanding by inexperienced users. While most of these were explained and justified, all are reasonable and required for solution.

The system provides the user with the capability to set acceptance levels for the statistical testing, to select and input different control limits, specifications, etc., to provide solutions to an infinite number of quality control problems, and to choose the ANOVA approach or the control chart approach.

This system, while designed for the situation at AiResearch could be adopted for use by anyone with quality

control situations either requiring or desiring a computerized approach to the control of quality. It is easily modifiable to fit any situation and is compatible with any processing system having FORTRAN IV capability.

Recommendations

Development of the quality control system as a solution to this study indicated a number of areas where improvements could be made to provide better and/or easier analysis.

First, redesign of the AiResearch test result form (CMR) to provide a better organized presentation of the data would allow a more rapid and complete analysis of the data. As an addendum, it would perhaps be more efficient to input the results directly through an on-site terminal (preferable) or a daily punched card input versus filing the CMR and extracting this data later. This approach could streamline and improve data collection.

An expansion of the data file format from that described in this report would be of benefit. Inclusion of the testing date, heat number, and results of additional tests run on a sample of material in one part No. file might be more logical and would require only minor format changes in order to be analyzed by use of the computer programs. This would allow a better chronological view of the process, and could be used instead of part number, test item number, and type of test to store the test data.

Also, application of MIL-STD-414[25] should be investigated for setting up of sampling plans. While the ASTM STP 15D[26] might provide a less costly, faster setting up of destructive testing plans, the MIL-STD recognizes the destructive testing situation and utilizes acceptable quality level (AQL) versus the OC curve. AQL is the quality level of the supplier's process that the consumer would consider to be acceptable as the process average for the purposes of acceptance sampling (9:153). This could conceivably reduce the necessary testing.

After identifying test data that exhibits "in-control" behavior and good equivalence between CERT and CMR data, it will be beneficial to study the flow patterns and analysis of variance results. It may be possible to eliminate testing at a particular location if it could be determined that the results of testing at a location were (statistically) always less or greater than that at another location. This could reduce testing costs and costs overall.

If testing of means and variances indicates equality between vendor and company testing, company and/or vendor testing could be reduced. If not, as in the test parts

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[25]MIL-STD-414, "Sampling Procedures and Tables for Inspection by Variables of Percent Defective" (21:57-70).

[26]ASTM STP 15D, American Society for Testing and Materials, "Manual on Presentation of Data and Control Chart Analysis" (1:71-146).

investigated in this report, the same level of testing should be retained and causes investigated. Such an approach, reminiscent of the MIL-STD-414 approach, could benefit not only in reduced cost, but better company vendor relations.

Modifying the plotting subroutine to draw connecting lines between the points would make trends easier to see. Also, if and when sufficient data becomes available, a histogram of the test data values would help to identify the underlying distribution.

As part of the vendor certification process, in the situation where a part is being supplied by more than one vendor, using the programs to indicate which vendor is producing the higher quality part can produce cost reductions by buying more from that producer resulting in possible lower cost per item, or by assigning a higher rating of reliability and/or reducing required testing level.

Finally, adapting the programs and quality control system to the new generation personal and business computers might allow a wider application of the system throughout the AiResearch Manufacturing Company, resulting in a better product at a lower cost--the goal of quality control.

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APPENDICES

APPENDIX A

APPENDIX A

USING THE QCC*PROGRAMS-- A USER'S MANUAL

Introduction

The QCC*Programs were designed to complement, in particular, the quality control system designed for the AiResearch Manufacturing Company evaluation of casting and forging acceptance testing. They have sufficient flexibility, however, to be applied to any problem requiring quality control charts and/or an analysis of data, so long as proper care is exercised in the application. The programs are written in FORTRAN IV, and while an extensive knowledge of this language is not required for using them, any modifications do require it, and should only be attempted by those who are intimately familiar with the program.

The programs produce $\overline{X}$- and R charts for grouped data, plot the individual values of the grouped data, provide analysis of variance and other statistics for grouped data, will group individual measurement data and produce grouped and individual measurement control charts for this data, and can provide statistics for testing the means of paired data groups.

Data Files

Data can be stored in any standard format; those shown here are used for illustration purposes only. The data must, however, be stored in a particular order to gain the desired result.

For the main program and subroutines

The first two lines or cards (an 80-column card; means the same as line in this manual) provide 72 spaces each to identify the contents of the file. The first line can be used to identify the type of information, dates the file covers, manufacturer, etc. and the second can identify the particular item with, for instance, a part number or description, etc.

The third line contains five values used in the program and are written in the following form.

```
NG          N          ISKIP          INLIM          IPLOT
III(no space)II(no space)II(no space)II(no space)II: FORMAT(I3,4I2)
I3          I2         I2             I2             I2
```

NG = Number of groups (MAX = 400)

N = Number of data points in each group (MAX 10)

= 0 = Program stops

ISKIP = Means of suppressing printing of means and ranges

= 0 = normal condition

> 0 = printing of means and ranges suppressed

INLIM = Means of suppressing use of calculated means and ranges

= 0 = normal condition

> 0 = use of calculated means and ranges suppressed; user must supply them; see final card description

IPLOT = Means of suppressing printing of the plot of individual values of grouped data (N>1)

= 0 = Normal condition

= 1 = no plot of individual values will be produced.

NOTE: If this card is blank, processing stops.

The fourth card states the format the data in the particular file is stored in. There are 72 available spaces here to describe this format. The suggested input for the card is:

FORMAT(I5,NF10.2) N(maximum) = 10

The I5 spaces at the beginning of each data group can be used to identify it with, for instance, a part number, date, etc. The design of the control charts allows only 5 characters to be used for this.

The fifth card contains the format for reading the labels that are to be applied to each N, if N>1. For example, the card might read:

FORMAT(4A4) (if N = 4)

and the sixth card, containing the labels applying to the individual N might read

POS3POS4POS5POS6

Thus for N_1 the label would be POS3 (corresponding to the position a sample was taken from), the N_2 label would be POS4, etc. The seventh card contains the minimum acceptable value for the data in the file in FORMAT(F10.3). If the card is blank, the program will consider F as a zero. The eighth card contains the first set of data in the format specified in card 4. For example,

1112ss132.5ssssss133.7sssss132.9sssss133.15s

is the data for part no. 1112 in the example format specified for card 4. NOTE: If this card is blank, it will be included in the data and plotting computations!!!

The final card of the data set will be the values for control chart means and limits, if the user has specified INLIM>0 in the format (6F10.0). *For our example, we might* know the characteristics of the population being sampled and wish to put in the following:

0sssssssss10.0ssssss22.0ssssss115.0sssss135.0sssss155.0

This option normally won't be used, unless a large historical bank of data is available.

In summary, then, the data file should consist of the following:

CARD	DESCRIPTION
1	72 spaces, FORMAT (18A4), for data identification
2	72 spaces, FORMAT (18A4), for data identification
3	FORMAT (I3,4I2) for specification of NG, N, ISKIP, INLIM, and IPLOT values

4 User-selected FORMAT for data--first 5 spaces formatted "I5"

5 User-selected FORMAT for labels to apply to each "N"

6 User-selected labels in FORMAT of card 5

7 FORMAT (F10.3) for value of minimum specification value

8 First data set in FORMAT of card 4

.

.

.

LAST FORMAT (6F10.0)-specification of range lower control limit (BCL), mean range (RBAR), range upper control limit (UCL), $\overline{X}$ lower control limit (BCLL), $\overline{X}$(XBAR) and $\overline{X}$ upper control limit (UCLL) if INLIM = 01 in card 3.

<u>For the TSTAR Program</u>

The first card in the program contains the number of data pairs (NG:MAX=400) and the value to be used in investigating the difference between the paired data (DMU) explained below.

The second card in the program provides 28 spaces and the third 24 spaces for data identification. The program, as it will be presented below, is set up to handle these two cards as a date (period of testing) on the second card and a part number on the third.

The fourth card is the first data card. Data is written in FORMAT (I5, 2F10.3) with the first 5 integer spaces used to identify the paired data and the other 20 (2 sets of 10 spaces) for the two values of the paired data). Any zero values on this card will be used in the calculations.

In summary, the data file for the TSTAR program should appear as follows:

CARD	DESCRIPTION
1	FORMAT (I4,F10.2) for specification of NG (number of groups/pairs), DMU (difference between means to be tested)
2	FORMAT (7A4); 28 spaces for data identification
3	FORMAT (24A1); 24 spaces for data identification
4	First data card in FORMAT (I5, 2F 10.0)

Program Operation

Control Chart Program

The control chart program is the director program for moving data through the appropriate subroutines to attain he user's desired result. This program is capable of directing analysis of variance and production of $\bar{X}$- and R-charts for grouped data (more than one data point, per group; N>1) with control limits of 3-, 2- and 1-sigma. It will also group individual data (only one data point per group) into groups of size 3 (or another value if the program is modified). These grouped individual data points are then used to

calculate control limits for 3- and 2-sigma $\bar{X}$ and R control charts and a control chart for the individual data is produced with the $\bar{X}$ (3-sigma) control limits. Finally, the program can produce a plot of all the values in the N>1 data situation in relation to their part number (or identification) along with the minimum specified value from the data file (card 7). This information can then be used to establish the need for further testing, verify a controlled situation (process, etc.) or of the other decisions that can be made using a control chart.

This program and the subroutines will automatically perform these operations when the data file is set up as described and the limits specified are adhered to. The only exception is in the event the input and output mediums are not "5" and "6," respectively, designating punch card input and printer output. These may differ in the user's system. In this event, lines 30 and 31 of the main program (LR [reader] and LW [writer]) must be changed to the proper values. Modifications to the program and subroutines are described in the section titled "Modification," below.

<u>TSTAR Program</u>

This program is designed to calculate the "T" statistic for paired, dependent data points that are normally distributed and will also yield the differences between the pairs for use in the non-parametric Wilcoxon paired "T" test. It can be used to determine if testing of

the same material by two different entities is producing equivalent results as well as if it is separated by a constant value (through specification of DMU, the different between the two to be investigated). It will yield not only the difference between each data pair, but also the difference squared (for calculating standard deviation), the totals of these, the sample variance and standard deviation, the average difference of all pairs, the degrees of freedom of the "T" statistic and the "T" statistic itself.

This program will automatically perform the operations just described as long as the procedures outlined are adhered to in setting up the data files. The only exception, as in the main program and subroutines, is if the input and output codes are not "5" and "6," respectively. All READ and WRITE statements will have to be changed to reflect the proper values (lines 11, 42-45, 47, 52, 54 & 59-60). The remainder of this manual will cover possibilities for tailoring the programs to the requirements of any specific situation or organization.

Modification

NOTE: THE FOLLOWING PARAGRAPHS ARE FOR MODIFICATION ONLY--THEY ARE NOT REQUIRED TO "RUN" THE PROGRAM!

Main Program

The main program (see printout in Appendix D) contains data tables, constants, FORMATS, and dimensions that can be

changed to accomodate most situations requiring quality control charts.

The first of these is the data table for the constant values for calculating the control limits. It could be expanded to include values for N(number of samples in a group)>10 in accordance with the values cited in the literature. Also, the table might be changed to use the sample standard deviation constants if the program was modified to calculate and use this in determining control limits.

If the values of N>10 and/or NG(number of groups)>400, the dimensions of X(), NSER(), HOLD() in line 8, LABEL() in line 10, and all in line 12 might have to be changed, along with *many of the "DO" instructions, etc.* Extreme care will have to be taken to re-dimension all appropriate items.

If the method of calculating the control limits is to be changed, lines 94 through 112 should be looked at closely. In most cases, it will be more advantageous to simply input the desired values utilizing the INLIM>0 option in the data file as described previously, versus a major program change.

Throughout the main program and subroutines, comment statements have been included to define variables, highlight important areas, and to clarify what operation is being performed.

Subroutine Charts

This subroutine, while designed to produce $\bar{X}$- and range charts could conceivably be used to produce other control charts. As can be seen in line 1, it uses values for limits, etc. that come from the main program so all that would be required is changing the titles to be printed at the top of the charts; line 105. Line 21, by the way, could also be changed to reflect a better description of the user's product.

As in the main program, increasing N greater than 10 and/or NG greater than 400 would require changes, but only in the DIMENSION line (11 & 12). KALER(), KALEX(), RANGE(), SUBAR() and M() would have to be increased to the maximum NG+3. The value +3 is used to allow for printing of the control limits and mean value in addition to the data points. If another value, such as a warning limit or upper specification limit, is to be used, these dimensions would have to be increased 1 for each additional value. Also, in this case, an additional figure to be used for plotting would have to be included in the DATA statement along with additional statements in the subroutine to allow their inclusion. Variables would have to be calculated or read in the main program and included in the COMMON/PLOT1/ statements so they would move between the program and subroutine CHARTS. Reference to lines 37 through 74 of CHARTS will aid in accomplishing such a modification. Note:

TMIN = specified minimum value read into the main program

M(I) = the "location" used to put this value in the chart array

IM = M = the "value" of the location M(I) that is printed on the chart

Subroutine SORTS

The only value that might be changed is the dimension of CH(), line 2, if max NG greater than 400 is used and/or there are additional points plotted in CHARTS.

Subroutine SCALE

No changes necessary.

Subroutine ASTATS

In the event a maximum NG greater than 400 is anticipated, or there are additional points plotted, the dimensions in line 10 would have to be increased to reflect the change.

This subroutine could, theoretically, be used to determine the values for calculating limits if another estimate of variation were to be used, such as sample standard deviation, etc. Such a calculation could be inserted in place of the calculations for range in lines 53 through 62.

Subroutine VALPLT

This subroutine plots the individual values for data groups with more than 1 value (i.e., N>1). It is the

author's opinion that more than 10 values (N>10) could make the plot crowded and meaningless, but if conditions warrant using this chart with N>10 (for instance, searching for one or two values out of a group of supposedly identical measurements), the subroutine could be so modified. It would probably be best in such a situation to convert the subroutine into a short program, although not necessary.

If N greater than 10 is to be utilized, then changes similar to those above are necessary. The dimensions of MON() and NAME(), line 12, would be increased to (N+1) and (N+5), respectively and an identifying label for each N would have to be included in the DATA statement, line 13. If the situation being investigated was searching for unequal values out of supposedly equal values, only those labels for the unequal values and one (the largest) of the equal values would be on the plot.

Finally, the FORMAT statements, lines 66-78, might require changes for labeling the chart.

Subroutine ANALVR

This subroutine performs the one- and two-way analyses of variance for grouped data (N>1) only. The only changes necessary would be to re-dimension TRT(), TRM(), SSPOS(), DIFSQR() and TSDEV() if N greater than 10 is desired and BLK() if NG greater than 400 is anticipated.

It also may be desired to have different statistical values used in the calculations displayed. This is easily

done by including the appropriate WRITE and FORMAT statements at the end of the subroutine. The WRITE statement must be placed in the deck prior to the return statement, and the FORMAT prior to the END.

TSTAR Program

This program, being rather specialized, requires, and is tolerant of, very little modification. The only values that could be changed are if NG greater than 400 is to be used, requiring DFF() and DIF2() of line 7 to be redimensioned and the length of the identification variables PNUM and DATE, requiring their redimensioning also. Note that if this is done, the FORMATS for titling the results table, lines 77 through 81, would have to be modified.

Conclusion

While modifications to the programs and subroutines require forethought and a knowledge of FORTRAN IV, they can be accomplished. The results of such changes could help save money, and improve the quality of a product or service. It may be that the programs you develop are more comprehensive than the author ever anticipated.

APPENDIX B

FORM 9734-6P

AIRESEARCH MANUFACTURING COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

IN REPLY REFER TO:
15-10340106

OFFICE MEMO

DATE: October 17,1978

TO: C. White DEPT. 84-80 101-2 COPIES TO: Distribution

FROM: R. Wagner DEPT. 93-391 EXT. 4066

SUBJECT: Critical Parts List & Applicable Specifications

After several meetings, the subject of which was the analysis of vendor generated and CMR data, it was the consensus of Materials Engineering, Quality Assurance and Manufacturing Engineering personnel that the use of control charts would be the best method. In order to initiate the program it was requested that Materials Applications prepare a list of the most critical components and the specifications which control them, such that the data could be collected and analyzed and thus control charts produced.

It is the goal to put the control charts into the EMS specification.

Tabulated below is a parts list for disks and wheels presently used on the ATF3-6, TFE731-2, -3, TPE331, GTCP660 and TSCP700 engines.

Part Name	Part No.	Material	Substantiation Testing Instructions (STI) Requirements	Metallurgical Control Specification
		ATF3-6		
Fan	3001249	Ti-6-4	5001 Cl.-1	EMS52458
Fan	3002539	Ti-6-4	5001 Cl.-1	EMS52458
1st Stg.Comp.	3002191	Ti-6-4	5001 Cl.-1	EMS52458
2nd Stg.Comp.	3002192	Ti-6-4	5001 Cl.-1	EMS52458
3rd Stg.Comp.	3002193	Ti-6-4	5001 Cl.-1	EMS52458
4th Stg.Comp.	3002194	Ti-6-4	5001 Cl.-1	EMS52458
5th Stg.Comp	3002145	Ti-6-4	5001 Cl.-1	EMS52458
HP Comp.	3002128	Ti-6-2-4-2Si	5001 Cl.-1	AF5395
HP Turbine	3001919	Astroloy	5001 Cl.-2	EMS52433
2nd Stg.Turbine	3001281	Waspaloy	5001 Cl.-2	EMS52449
3rd Stg.Turbine	3001282	Waspaloy	5001 Cl.-2	EMS52449
4th Stg.Turbine	3001283	Waspaloy	5001 Cl.-2	EMS52449
5th Stg.Turbine	3002095	Super Waspaloy	5001 Cl.-1	EMS52434
6th Stg.Turbine	3002097	Super Waspaloy	5001 Cl.-1	EMS52434
		TFE731-2, -3		
Fan	3072162	Ti-6-4	5001 Cl.-2	EMS52458
1st Stg.Comp.	3072193	Ti-6-4	5001 Cl.-1	AF5395
2nd Stg.Comp.	3072191	Ti-6-4	5001 Cl.-1	AF5395
3rd Stg.Comp.	3072192	Ti-6-4	5001 Cl.-1	AF5395

TO: C. White

15-10340106
Page. . . 2

Part Name	Part No.	Material	Substantiation Testing Instruct. (STI) Requirements	Metallurgical Control Specification
		TFE731-2, -3		
4th Stg.Comp.	3072193	Ti-6-4	5001 Cl.-1	AF5395
HP Comp.	3072639 3070274	Ti-6-2-4-2Si	5001 Cl.-1	AF5395
HP Turbine	3072112	Astroloy	5001 Cl.-1or2	EMS52476
HP Turbine	3072316	Waspaloy	5001 Cl.-2	EMS52449
1st Stg.Turbine	3072070	Waspaloy	5001 Cl.-2	EMS52449
1st Stg.Turbine	3072351	Waspaloy	5001 Cl.-2	EMS52449
2nd Stg.Turbine	3072069	Waspaloy	5001 Cl.-2	EMS52449
3rd Stg.Turbine	3072068	Waspaloy	5001 Cl.-2	EMS52449
		TPE331		
1st Stg.Comp.	868219	Ti-6-4	5001	-
1st Stg.Comp.	896223	Ti-6-4	No SCS	-
2nd Stg.Comp.	868220	Ti-6-4	5001	-
1st Stg.Turbine	867569 (867571-25)	IN-100	5000	-
1st Stg.Turbine	3101520	Waspaloy	5001	EMS52449
2nd Stg.Turbine	868272	IN-100	5000	EMS52466
2nd Stg.Turbine	3101514	IN-100	5000	EMS52466
3rd Stg.Turbine	867571-11	IN-713LC	5000	AF5358
3rd Stg.Turbine	895539	IN-713LC	5000	AF5358
3rd Stg.Turbine	868630	IN-713LC	5000	AF5358
3rd Stg.Turbine	3101516	Waspaloy	5001	EMS52449
3rd Stg.Turbine	3101660	IN-713LC	5000	AF5358
		GTCP660		
1st Stg.Comp.	977328	Ti-6-4	5001 Cl.-10	AF5395
2nd Stg.Comp	968819	Ti-6-4	5001 Cl.-10	AF5395
3rd Stg.Comp.	968822	Ti-6-4	5001 Cl.-10	AF5395
4th Stg.Comp.	968825	Ti-6-4	5001 Cl.-10	AF5395
1st Stg.Turbine	892812	Waspaloy	5001 Cl.-2	EMS52449
2nd Stg.Turbine	892813	Waspaloy	5001 Cl.-2	EMS52449
		TSCP700		
1st Stg.Comp.	969600	Ti-6-4	5001 Cl.-10	AF5395
1st Stg.Comp.	3606429	Ti-6-4	5001 Cl.-10	AF5395
2nd Stg.Comp.	977201	Ti-6-4	5001 Cl.-9or10	AF5395
3rd Stg.Comp.	977200	Ti-6-4	5001 Cl.-9or10	AF5395
HP Comp.	3601186	Ti-6-4	5001 Cl.-9	AF5395
HP Turbine	977156	Waspaloy	5001 Cl.-2	EMS52449
1st Stg.Turbine	969562	Waspaloy	5001 Cl.-5	EMS52449
2nd Stg.Turbine	969561	Waspaloy	5001 Cl.-2	EMS52449

669-1 669-2

MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. EMS55389	REV LTR E

1. APPLICATION

1.1 This specification is applicable to forging stock and forgings used primarily for turbine disks at operating temperatures up to 1700°F.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent referenced herein.

2.1.1 Government Publications - Federal Test Method Standard No. 151 - Metals; Test Methods

2.1.2 Aerospace Material Specifications

AMS 2261 - Tolerances, Nickel, Nickel Base, and Cobalt Base Alloy Bars and Forging Stock

AMS 2269 - Chemical Check Analysis Limits, Wrought Nickel and Nickel Base Alloys

AMS 2808 - Identification, Forgings

2.1.3 American Society for Testing and Materials Specifications

ASTM E 8 - Tension Testing of Metallic Materials

ASTM E 10 - Brinell Hardness of Metallic Materials

ASTM E 112 - Estimating Average Grain Size of Metals

ASTM E 139 - Conducting Creep and Time-for-Rupture Tension Tests of Materials

ASTM E 354 - Chemical Analysis of High-Temperature, Electrical, Magnetic, and Other Similar Iron, Nickel, and Cobalt-Base Alloys

3. TECHNICAL REQUIREMENTS

3.1 Chemical composition shall conform to the following percentages by weight, determined by wet chemical methods in accordance with ASTM E 354, or by spectrographic methods in accordance with Federal Test Method Standard No. 151, Method 112:

Carbon	0.03 - 0.09
Manganese	0.15 max.
Sulfur	0.015 max.
Phosphorus	0.015 max.
Silicon	0.10 max.
Cobalt	16.0 - 18.0
Chromium	14.0 - 16.0
Molybdenum	4.5 - 5.5
Titanium	3.25 - 3.75
Aluminum	3.75 - 4.25
Boron	0.02 - 0.03
Iron	0.50 max.
Copper	0.10 max.
Zirconium	0.05 max.
Nickel	Remainder

3.1.1 Variations shall conform to the requirements of AMS 2269.

3.2 Condition

3.2.1 Forgings - Forgings shall be in the following condition unless otherwise specified: Condition A - solution- and stabilization-heat-treated; Condition B - stabilization-heat-treated only; Condition C - solution-heat-treated and stabilization-heat-treated only.

3.2.2 Forging Stock - As ordered by the forging manufacturer.

3.3 Forgings (Condition A) - Forgings requiring maximum elevated-temperature stress-rupture properties.

3.3.1 The forging shall be solution-heat-treated at a selected temperature and time, and cooled at a rate to obtain the specified properties.

3.3.2 Stabilize at 1975°F ±25 for 4 hours and cool at a rate equivalent to a rapid air-cool.

3.3.3 Precipitation heat treat at 1550°F ±25 for 4 hours and air-cool. Heat to 1400°F for 16 hours and air-cool.

3.3.4 Properties after Precipitation Heat Treatment - Test specimens shall be taken from the locations shown in Figure 1.

3.3.4.1 Tensile test specimens cut from the forging and tested at room temperature shall conform to the following requirements:

Yield strength (0.2 percent offset), psi	130,000 min
Ultimate tensile strength, psi	170,000 min
Elongation, percent in 4D	6.0 min
Reduction of area, percent	6.0 min

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MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. EMS55389	REV LTR E

3.3.4.2 Stress-rupture specimens cut from the forgings shall be maintained at 1800°F ±5, under a continuously applied axial stress of 20,000 psi, and shall not rupture in less than 30 hours. The test shall be continued to rupture and the elongation, measured at room temperature, shall not be less than 5 percent in 4D.

3.3.4.3 The Brinell hardness shall be 300 to 400.

3.3.4.4 Solution-heat-treated forgings shall have a uniform grain size of ASTM 2 or finer, with occasional grains as large as 0 permissible, as determined by comparison of a polished and etched specimen with the chart in ASTM E 112.

3.4 Forgings (Condition B) - Forgings with maximum operating temperature of 1500°F, requiring maximum tensile properties.

3.4.1 The forging shall be stabilized at 1975°F ±25 for 4 hours and cooled at a minimum rate equivalent to air-cooling.

3.4.2 Precipitation heat treat at 1550°F ± 25 for 4 hours and air-cool. Heat at 1400°F ± 25 for 16 hours and air-cool

3.4.3 Properties after Precipitation Heat Treatment - Test specimens shall be taken from the locations shown in Figure 1.

3.4.3.1 Tensile test specimens cut from the forging and tested at room temperature shall conform to the following requirements:

Yield strength (0.2 percent offset), psi	140,000 min
Ultimate tensile strength, psi	185,000 min
Elongation, percent in 4D	10.0 min
Reduction of area, percent	10.0 min

3.4.3.2 Stress-rupture specimens cut from the forging shall be maintained at 1400°F ±5 under a continuously applied axial stress of 85,000 psi, and shall not rupture in less than 23 hours. The test shall be continued to rupture and the elongation, measured at room temperature, shall not be less than 3 percent in 4D.

3.4.3.3 Stress-rupture specimens cut from the forging shall be maintained at 1800°F ±5 under a continuously applied axial stress of 18,000 psi until rupture. The elongation measured at room temperature and stress-rupture life shall be reported.

3.4.3.4 The Brinell hardness shall be 300 to 400.

3.4.3.5 Stabilization-heat-treated forgings shall have a substantially uniform grain size of ASTM 3 or finer, with occasional grains as large as 1 permissible, as determined by comparison of a polished and etched specimen with the chart in ASTM E 112. When a dispute over grain size results, the Heyn's intercept method shall be used.

3.5 Forgings (Condition C) - Forgings requiring maximum tensile and creep properties up to 1500°F.

3.5.1 Solution heat treat at a temperature within the range 1975-2075°F, hold at the selected temperature ±15°F for four hours, and quench into molten salt bath at 600°F ±10; stabilize at bath temperature, and air cool. Parts may be oil quenched if configuration permits.

3.5.2 Stabilize at 1600°F ±15 for eight hours, and cool to room temperature at a rate equivalent to air-cool; heat to 1800°F ±15, hold at heat for four hours, and cool at a rate equivalent to air-cool.

3.5.3 Precipitation heat treat at 1200°F ±25 for 24 hours, and air-cool to room temperature; heat to 1400°F ±25, hold at heat for eight hours, and air-cool.

3.5.4 Properties after Precipitation Heat Treatment - Test specimen location shall be as specified.

3.5.4.1 Tensile test specimens cut from the forging and tested at room temperature shall conform to the following requirements:

Yield strength (0.2 percent offset), psi	140,000 min
Ultimate tensile strength, psi	195,000 min
Elongation, percent in 4D	16 min
Reduction of area, percent	18 min

3.5.4.2 Tensile test specimens cut from the forging and tested at 1400°F ±10 shall conform to the following requirements:

Yield strength (0.2 percent offset), psi	125,000 min
Ultimate tensile strength, psi	150,000 min
Elongation, percent in 4D	20 min
Reduction of area, percent	30 min

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MATERIAL SPECIFICATION	CODE IDENT NO 99193	SPECIFICATION NO. EMS55389	REV LTR E

3.5.4.3 Stress-rupture specimens cut from the forgings shall be maintained at 1400°F ±5, under a continuously applied axial stress of 85,000 psi, and shall not rupture in less than 30 hours. The test shall be continued to rupture and the elongation, measured at room temperature, shall not be less than 17 percent in 4D.

3.5.4.4 A smooth specimen shall be maintained at 1300°F ±5 under continuously applied stress of 74,000 psi. Time to 0.1 percent plastic deformation shall average not less than 150 hours, with no value below 110 hours. Creep measurements shall be taken until 0.1 percent plastic extension is attained. Gauge dimensions of specimens and techniques used to measure creep shall be as agreed upon by purchaser and supplier.

3.5.4.5 The Brinell hardness shall be 313 to 403.

3.5.4.6 Fully heat-treated forgings shall have a substantially uniform grain size of ASTM 4 or finer, with occasional grains as large as 3 permissible, as determined by comparison of a polished and etched specimen with the chart in ASTM E 112. When a dispute over grain size results, the Heyn's intercept method shall be used.

3.6 Forging Stock

3.6.1 When a sample of forging stock is forged to a test coupon and heat treated as in Paragraph 3.3, 3.4 or 3.5, test specimens taken from the heat-treated coupon shall have properties as specified in Paragraphs 3.3, 3.4 or 3.5, as applicable.

3.6.2 If test specimens taken from the forging stock after heat treatment conform to the requirements of Para. 3.3, 3.4 or 3.5, as applicable, the tests shall be accepted as equivalent to the tests of the forged coupon of 3.6.1. Neither of these tests is required in routine inspection.

4. PROCESS CONTROL

4.1 Forgings shall be supplied descaled unless otherwise specified.

5. INSPECTION

5.1 Tolerances shall be in accordance with AMS 2261.

5.2 Tensile testing shall be performed in accordance with ASTM E 8.

5.3 Stress-rupture testing shall be performed in accordance with ASTM E 139.

5.4 Hardness shall be determined in accordance with ASTM E 10.

6 IDENTIFICATION

6.1 Forgings shall be identified in accordance with AMS 2808.

6.2 The forging serial number shall be traceable to the billet, position in the billet, forging lot identification, and mill heat identification.

7. APPROVAL AND PROCUREMENT

7.1 If necessary to make any change in equipment, procedures, or techniques after approval is granted, the source (forging or material) making the change shall obtain written permission from AiResearch Materials Engineering and Manufacturing Engineering Casting/Forging Design prior to the first shipment incorporating such a change.

8. REPORTS

8.1 The supplier of forgings shall furnish to AiResearch Receiving Inspection with each shipment a report of chemical composition test results of each heat in the shipment and test results of each size from each heat to determine conformance to the technical requirements of this specification. This report shall include the purchase order number, material specification number and its revision letter, heat number, size, and quantity from each heat. The forging part number and the size of stock used to make the forgings shall also be included.

8.2 The supplier of finished or semifinished parts shall furnish to AiResearch Receiving Inspection with each shipment a report showing the purchase order number, material specification number and its revision letter, name of contractor or other direct supplier of material, part number, and quantity. When material for making parts is produced or purchased by the parts supplier, that supplier shall inspect each lot of material to determine conformance to the requirements of this specification, and shall include in his report a statement that the material conforms, or shall include copies of laboratory test reports showing the results determining conformance.

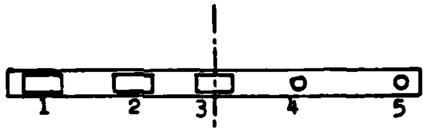
9. QUALITY CONTROL

9.1 Forging stock shall be produced by vacuum-induction melting or by vacuum-induction melting followed by vacuum-arc remelting.

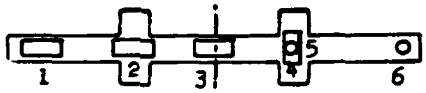
9.2 Forgings shall have substantially uniform macrostructure and grain flow.

9.3 The product, as received by the purchaser, shall be uniform in quality and condition, sound, and free from foreign materials and from internal and external imperfections detrimental to usage of the product.

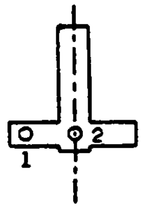
9.4 Material not conforming to the requirements of this specification shall be rejected.



A: FLAT DISK CONFIGURATIONS



B: INTEGRAL COUPLING DISK CONFIGURATIONS



C: INTEGRAL SHAFT DISK CONFIGURATIONS

NOTE: A: DISKS LESS THAN 6 INCHES IN DIAMETER USE ONLY SAMPLES 1, 3 AND 5. STRESS-RUPTURE SAMPLES FROM RIM AREA POSITIONS 1 AND 5, RT TENSILES FROM POSITIONS 2, 3 AND 4.

B: POSITIONS 1 AND 6 TO BE USED FOR STRESS-RUPTURE, POSITIONS 2,3,4 AND 5 TO BE USED FOR RT TENSILES.

C: POSITION 1 FOR STRESS-RUPTURE, POSITION 2 FOR RT TENSILE. ON DISK DIAMETERS LARGER THAN 6 INCHES, OTHER TEST LOCATIONS MAY APPLY.

FIGURE 1

TEST SPECIMEN LOCATIONS
FOR FORGED TURBINE DISKS

99-1 99-2

MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. EMS52476	REV LTR C

1. APPLICATION

1.1 This specification provides metallurgical control procedures and acceptance criteria for forged Astroloy Condition A turbine disks specified with or specified without integrally forged test rings.

1.1.1 Forged components shall be classed as follows:

Class I - Forgings required to have integrally forged test rings.

Class II - Forgings without integrally forged test rings.

1.1.2 If no class is specified, Class I shall apply.

1.2 The following manufacturing procedures and controls are specified:

1.2.1 Fixed-process verification

1.2.2 Forging lot control

1.3 The following inspection procedures and tests are specified:

1.3.1 Nondestructive mechanical-property testing

1.3.2 Destructive mechanical-property testing

1.4 The following terms used in this specification shall have the meaning as defined below:

1.4.1 Forging Lot Definitions

1.4.1.1 Class I - All forgings made consecutively, to the final configuration, from a single master heat, without removal of the dies from the forging equipment.

1.4.1.2 Class II - Less than or equal to 33 forgings, made consecutively, to the final configuration, from a single master heat, without removal of the dies from the forging equipment.

1.4.1.3 A forging lot number is a number assigned to a forging lot.

1.4.2 When one hundred (100) percent inspection is specified, the forging vendor shall perform one tensile test at room temperature on a specimen taken from the integrally forged test ring from each forging in all forging lots.

1.4.2.1 One hundred (100) percent inspection applies only to Class I forgings.

1.4.3 A forging sample is a sample selected at random from a forging lot.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent referenced herein.

2.1.1 AiResearch Specifications

EMS55389 Alloy, Corrosion- and Heat-Resistant, Nickel-Base 15 Cr-17 Co-5 Mo-3.5 Ti-4 Al-0.025B (Astroloy and Udimet 700)

EMS52406 Forgings, General

EMS52321 Ultrasonic Inspection

EMS52309 Fluorescent-Penetrant Inspection

2.1.2 American Society for Testing and Materials

E 8-Tension Testing of Metallic Materials

3. TECHNICAL REQUIREMENTS

3.1 All requirements of EMS55389 shall apply except that the minimum mechanical-property requirements shall be as specified herein.

3.2 Forging Identification

3.2.1 Each forging shall be identified by a part number and a forging lot number to provide traceability to starting mill heat number. When specified, each forging shall also be identified by a serial number to provide traceability to starting billet number and position within the billet.

3.3 Condition

3.3.1 Heat-treated in accordance with EMS55389 Condition A unless otherwise specified.

3.3.1.1 Forgings with their test rings intact shall be solution and stabilization heat-treated.

3.4 Mechanical Properties

3.4.1 Test specimens taken from forgings and test rings shall be in the fully heat-treated condition and shall exhibit the minimum properties specified in Table I.

3.5 Fixed Process Verification

3.5.1 The vendor shall establish a fixed process in accordance with EMS52406.

99-3 99-4

MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. EMS52476	REV LTR C

3.6 Forging Lot Control

3.6.1 Nondestructive Testing Requirements

3.6.1.1 A 100-percent inspection shall be performed on all Class I forging lots by the forging vendor until sufficient statistical data is obtained and reversion to a lot sampling method is agreed upon via established procedures.

3.6.1.2 A 100-percent inspection of all Class I forgings shall be accomplished by any new forging vendor until sufficient test data has been obtained to justify a statistical sampling method.

3.6.1.3 A 100-percent inspection shall be accomplished by any forging vendor when there has been an agreed-upon permanent change in the forging process and until sufficient data has been obtained to justify a new sampling method.

3.6.1.4 When the forging vendor has made an inadvertent change in the fixed process during the production of forgings, except as noted, and when approval through AiResearch has been obtained, then 100-percent inspection shall be accomplished for those forgings.

3.6.1.5 If any of the test ring tensile properties are below minimum, two additional test bars from the same test ring shall be tested. If the values of the retests from the test ring exceed the minimum values, the forging is to be accepted. If either of the retests falls below the minimum, that forging shall be rejected.

3.6.2 Destructive Mechanical-Property Testing

3.6.2.1 A forging sample for destructive testing shall also be taken from each production forging lot by the forging vendor.

3.6.2.2 The forging vendor shall perform the destructive testing on test specimens removed from each sample forging, as specified.

3.6.2.3 One-half of each sample forging shall be sent to AiResearch.

4. INSPECTION

4.1 Each forging shall be acid etched and visually inspected in accordance with Appendix I at 4X minimum magnification.

4.2 Each forging shall then be fluorescent-penetrant inspected in accordance with EMS52309, Class 1, using a Group V penetrant.

4.3 When ultrasonic inspection is specified, each forging shall be inspected in accordance with EMS52321, and the appropriate class. The class of inspection shall be determined by the maximum cross-sectional thickness of the forging, as follows:

Thickness (inches)	Class of Inspection
0-1	I
Over 1-2	II
Over 2-3.75	III

4.3.1 For thicknesses over 3.75 inches, consult AiResearch Quality Assurance for alternate methods of inspection.

4.4 All Class I and Class II forging samples shall be tested for mechanical properties.

4.4.1 The vendor shall remove and test the specified integrally forged test ring from each forging.

4.4.1.1 When serialization is required, the test ring shall bear the same serial number as the forging from which it was removed.

4.4.2 Tensile specimens shall be machined and tested in accordance with ASTM E 8.

5. APPROVAL OR PROCUREMENT

5.1 One-half of each sample forging selected from each production lot for destructive mechanical-properties testing shall be forwarded to AiResearch.

5.2 The forging vendor shall store the integrally forged test rings for a period of two years from the date of the test reported, and these rings shall be made available to AiResearch upon request.

6. QUALITY CONTROL

6.1 A test report shall be sent to AiResearch Receiving Inspection with each shipment and shall indicate the forging lot number and quantity represented and, when serialization is required, each serial number represented.

6.2 The test report shall list the results of the destructive lot sample tests and the tensile results from all test rings representing the shipped forgings by lot number and, when serialization is required, by serial number.

6.3 One-half of each sample forging selected for destructive testing shall be shipped prior to or with the first production forging from the lot. A list of serial numbers in the lot shall be submitted with each sample forging, when serialization is required.

6.4 Forgings not conforming to this specification shall be rejected.

MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. EMS52476	REV LTR -

TABLE I

MECHANICAL PROPERTIES
(Minimum)

Test	Temp (±5°F)	Stress (psi)	Test Time (hrs)	Ultimate (psi)	Yield 0.2% Offset (psi)	Elongation (% in 4D)	Reduction of Area (%)
Tensile	Room	-	-	170,000	130,000	6	6
	*1200	-	-	Report	Report	Report	Report
Stress Rupture (Smooth)	1400	85,000	30	-	-	5	-

*Elevated 1200°F temperature tensile test results are to be reported.

MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. EMS52449	REV LTR D

1. APPLICATION

1.1 This specification provides metallurgical control procedures and acceptance criteria for forged Waspaloy turbine components specified with or specified without integrally forged test rings.

1.1.1 Forged components shall be classed as follows:

Class I - Forgings required to have integrally forged test rings.

Class II - Forgings without integrally forged test rings.

1.1.2 If no class is specified, Class I shall apply.

1.2 The following manufacturing procedures and controls are specified:

1.2.1 Fixed-process verification

1.2.2 Forging lot control

1.3 The following inspection procedures and tests are specified:

1.3.1 Nondestructive mechanical-property testing

1.3.2 Destructive mechanical-property testing

1.4 The following terms used in this specification shall have the meaning as defined below:

1.4.1 Forging Lot Definitions

1.4.1.1 Class I - All forgings made consecutively, to the final configuration, from a single master heat, without removal of the dies from the forging equipment.

1.4.1.2 Class II - Less than or equal to 33 forgings, made consecutively, to the final configuration, from a single master heat, without removal of the dies from the forging equipment.

1.4.1.3 A forging lot number is a number assigned to a forging lot.

1.4.2 One hundred (100) percent inspection requires the forging vendor to perform two tensile tests--one at room temperature and one at 1000°F--on specimens taken from the integrally forged test ring from each forging in all forging lots.

1.4.2.1 One hundred percent inspection applies only to Class I forgings.

1.4.3 A forging sample is a forging selected at random from a forging lot.

2. APPLICABLE DOCUMENTS

2.1 The following documents are a part of thi specification to the extent referenced herein.

2.1.1 AiResearch Specifications

EMS55388	Alloy, Corrosion- and Heat-Resistant, Nickel-Base 19.5 Cr-13 Co-4 Mo-1.4 Al Multiple Vacuum Melted Solution Heat-Treated (Waspaloy)
EMS52406	Forgings, General
EMS52321	Ultrasonic Inspection
EMS52309	Fluorescent-Penetrant Inspection
MC5014	Marking and Traceability Requirements

3. TECHNICAL REQUIREMENTS

3.1 Forging Identification

3.1.1 Each forging shall be identified by a part number and a forging lot number to provide traceability to starting mill heat number. When specified, each forging shall also be identified by a serial number to provide traceability to starting billet number and position within the billet.

3.2 Condition

3.2.1 Solution heat-treated in accordance wit EMS55388 unless otherwise specified.

3.2.1.1 The forging vendor shall solution heat-treat each forging.

3.2.2 After solution heat treatment, and prior to mechanical-property testing, each test ring shall be stabilized and precipitatio heat-treated as specified.

3.2.2.1 If the forgings are to be supplied in the solution heat-treated condition, the test rings shall be separated from the forgings after solutioning, then stabilized and precipitation heat-treated prior to testing.

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3.2.2.2 If the forgings are ordered in the fully heat-treated condition, the integral test rings shall be attached to the forgings during stabilization and precipitation heat-treatment, then removed and tested.

3.2.3 Stabilization Heat Treatment - Heat to 1550°F ±25°F, hold at heat for 4 hours, cool in air.

3.2.4 Precipitation Heat Treatment - Heat to 1400°F ±25°F, hold at heat for 16 hours, cool in air.

3.3 Test specimens taken from forgings and test rings shall be in the fully heat-treated conditions and shall exhibit the minimum properties specified in EMS55388.

3.4 Fixed Process Verification

3.4.1 The vendor shall establish a fixed process in accordance with EMS52406. The established fixed process shall be submitted to AiResearch for approval prior to acceptance of production parts.

3.4.2 If it becomes necessary for the vendor to make any change in the fixed process, written approval and disposition shall be obtained from AiResearch in accordance with established procedures.

3.4.3 Each supplier shall keep on file, for the period of time specified in MC5014, the daily records of all control items in the fixed process that are recorded continuously on strip charts or circular charts or checked and recorded by hand. All process controls shall be personally audited by the supplier's quality control section once every month and a report filed.

3.5 Forging Lot Control

3.5.1 Nondestructive Testing Requirements

3.5.1.1 A 100-percent inspection shall be performed on all Class I forging lots by the forging vendor until sufficient statistical data is obtained and reversion to a lot sampling method is agreed upon via established procedures.

3.5.1.2 A 100-percent inspection of all Class I forgings shall be accomplished by any new forging vendor until sufficient test data shall have been obtained to justify a statistical sampling method.

3.5.1.3 A 100-percent inspection shall be accomplished by any forging vendor when there has been an agreed-upon permanent change in the forging process and until sufficient test data shall have obtained to justify a new sampling method.

3.5.1.4 When the forging vendor has made an inadvertent change in the fixed process during the production of forgings, except as noted, and when approval through Airesearch has been obtained, then 100-percent inspection shall be accomplished for those forgings.

3.5.1.5 If any of the test ring tensile properties are below minimum, two additional test bars from the same test ring shall be tested. If the values of the retests from the test ring exceed the minimum values, the forging is to be accepted. If either of the retests falls below the minimum, that forging shall be rejected.

3.5.2 Destructive Mechanical-Property Testing

3.5.2.1 A forging sample for destructive testing shall also be taken from each production forging lot by the forging vendor.

3.5.2.2 The forging vendor shall perform the destructive testing on test specimens removed from each sample forging, as shown in Figure 1, in accordance with EMS55388.

3.5.2.3 One-half of each sample forging shall be sent to AiResearch.

4. INSPECTION

4.1 Each forging shall be acid etched and visually inspected in accordance with Appendix I.

4.2 Each forging shall then be fluorescent penetrant inspected in accordance with EMS52309, Class 1, using a Group V penetrant.

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4.3 Each forging shall be ultrasonic inspected in accordance with EMS52321 and the appropriate class. The class of inspection shall be determined by the maximum cross-sectional thickness of the forging, as follows:

Thickness (inches)	Class of Inspection
0-1	I
over 1-3	II
over 3-5	III
over 5-7	IV

4.3.1 If pancake forgings with flat, parallel faces are produced as an intermediate forging operation, these forged pancakes may be ultrasonically inspected in lieu of the finished forging.

4.3.1.1 The thickness dimension of the forged pancake shall be substituted for the maximum cross-sectional thickness of the finished forging in order to determine the ultrasonic inspection classification.

4.4 All Class I and Class II forging samples shall be tested for mechanical properties.

4.4.1 The vendor shall remove and test the specified integrally forged test ring from each forging.

4.4.1.1 When serialization is required, the test ring shall bear the same serial number as the forging from which it was removed.

4.4.2 Tensile test specimens shall be machined with 0.250-inch reduced sections and a 1-inch minimum gauge length.

4.4.3 Tensile test specimens shall be strained at a rate of 0.005-inch per inch per minute, and the rate may be increased to 0.02-inch per inch per minute for strains beyond the yield point.

5. APPROVAL OR PROCUREMENT

5.1 One-half of each sample forging selected from each production lot for destructive mechanical-properties testing shall be forwarded to AiResearch.

5.2 The forging vendor shall store the integrally forged test rings for a period of two years from the date of the test reported, and these rings shall be made available to AiResearch upon request.

6. QUALITY CONTROL

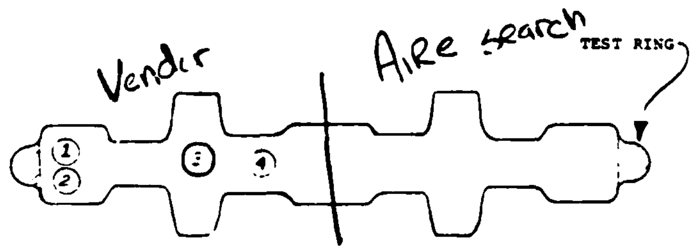
6.1 A test report shall be sent to AiResearch Receiving Inspection with each shipment and shall indicate the forging lot number and quantity represented and, when serialization is required, each serial number represented.

6.2 The test report shall list the results of the destructive lot sample tests and the tensile results from all test rings representing the shipped forgings by lot number and, when serialization is required, by serial number.

6.3 The test results shall meet the requirements of EMS55388.

6.4 One-half of each sample forging selected for destructive testing shall be shipped prior to or with the first production forging from the lot. A list of serial numbers in the lot shall be submitted with each sample forging, when serialization is required.

6.5 Forgings not conforming to this specification shall be rejected.



POSITION 1 COMBINATION STRESS RUPTURE
POSITION 2 SMOOTH STRESS RUPTURE
POSITION 3 1000°F TENSILE
POSITION 4 ROOM-TEMPERATURE TENSILE

FIGURE 1 - DESTRUCTIVE TEST SPECIMEN REQUIREMENTS FOR FORGED WASPALOY TURBINE DISKS.

MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. EMS55388	REV LTR C

1. APPLICATION

1.1 This material is primarily for turbine disks, shafts, bolts and fittings operating to 1600°F.

1.2 This document defines the requirements for forgings and cross-rolled plate in Conditions A, B, and C, as specified.

Condition A - Material requiring maximum stress-rupture properties.

Condition B - Material requiring maximum tensile properties.

Condition C - Thermal-mechanically processed (TMP) material.

1.3 The following terms used in this specification shall have the meaning as defined below:

1.3.1 TMP refers to thermal mechanical processing, which involves warm working below the recrystallization temperature.

1.3.2 Cross-rolling consists of carefully controlling reductions throughout deformation processing from ingot to final product so that there are essentially equal amounts of elongation in the two orthogonal directions of width and length.

2. APPLICABLE DOCUMENTS

2.1 The following documents form a part of this specification to the extent referenced herein.

2.1.1 ASTM Specifications

E 8	Tension Testing of Metallic Materials
E 112	Average Grain Size of Metals, Estimating the

2.1.2 AMS Specifications

AMS 2261	Tolerances - Nickel, Nickel Base, and Cobalt Base Alloy Bars and Forging Stock
AMS 2269	Chemical Check Analysis Limits - Wrought Nickel and Nickel Base Alloys

2.1.3 AiResearch Specifications

MC5014	Marking and Traceability Requirements

3. TECHNICAL REQUIREMENTS

3.1 Composition

Carbon	0.10 max
Manganese	0.50 max
Silicon	0.75 max
Sulfur	0.015 max
Chromium	18.00 - 21.00
Cobalt	12.00 - 15.00
Molybdenum	3.50 - 5.00
Titanium	2.75 - 3.25
Aluminum	1.20 - 1.60
Zirconium	0.02 - 0.12
Boron	0.01 max.
Iron	2.00 max
Copper	0.10 max
Nickel	Remainder

3.1.1 Composition variations shall meet the requirements of the latest issue of AMS 2269.

3.2 Condition

3.2.1 Forging and cross-rolled plate stock shall be supplied as ordered by the manufacturer.

3.2.2 Forgings and cross-rolled plate shall be supplied solution heat treated and descaled, unless otherwise specified.

3.3 Heat Treatment

3.3.1 Solution Heat Treatment (Conditions A and B): Condition A and B forgings and cross-rolled plate shall be heated to a temperature within the range of 1825 to 1900°F, held at this selected temperature within ±25°F for 4 hours, then cooled rapidly in air, oil or water.

3.3.2 Solution Heat Treatment (Condition C): In lieu of the solution heat treatment specified above, Condition C forgings and cross-rolled plate shall be given a modified solution heat treatment at a temperature below the gamma-prime solvus temperature in accordance with the supplier's fixed process.

3.3.3 Stabilization Heat Treatment (Conditions A, B and C): Heat to 1550 ±25°F, hold at heat for 4 hours, cool in air.

3.3.4 Precipitation Heat Treatment (Conditions A, B and C): Heat to 1400 ±25°F, hold at heat for 16 hours, cool in air.

3.4 Mechanical Properties

3.4.1 Condition A

3.4.1.1 Tensile test specimens cut from forgings or cross-rolled plate and tested at room temperature in accordance with ASTM E 8 shall meet the following minimum requirements:

Ultimate tensile strength, psi	160,000
Yield strength, (0.2 percent offset) psi	110,000
Elongation, percent in 4D	12.0
Reduction of area, percent	15.0

3.4.1.2 Condition A Stress-Rupture Properties: Specimens cut from forgings or cross-rolled plate shall be tested under the following conditions.

3.4.1.2.1 A smooth test specimen shall be maintained at 1500 ±5°F, under a continuously applied axial stress of 47,500 psi, and shall not rupture in less than 23 hours. The test shall be continued to rupture, and elongation after rupture, measured at room temperature, shall be a minimum of 5 percent in 4D.

3.4.1.2.2 A combination smooth and notched test specimen, machined to the dimensions of Figure 1, shall be maintained at 1350 ±5°F under a continuously applied axial stress of 80,000 psi and shall not rupture in less than 23 hours. The test shall be continued to rupture. Failure of the smooth section shall not occur in less than 23 hours, but it shall fail in less time than the notched section. Elongation of the smooth section after rupture shall be a minimum of 5 percent in 4D, measured at room temperature.

3.4.1.2.3 Separate smooth and notched test specimens, machined from adjacent sections of the same piece with gauge sections conforming to the respective dimensions of Figure 1, may be tested as an alternate procedure, using the same test conditions. The smooth specimen shall not rupture in less than 23 hours, and elongation after rupture measured at room temperature shall be not less than 5 percent in 4D. The notched specimen need not be tested to rupture, but rupture shall not occur in less time than the smooth section.

3.4.1.2.4 The tests may be conducted at a higher stress level, but the stress shall not be increased while the test is in progress. Time to rupture and elongation requirements shall be as specified.

3.4.1.3 Hardness of the fully heat-treated material shall be Brinell 313 to 403.

3.4.1.4 Grain Size: Forgings and cross-rolled plate heat treated to meet the property requirements of Condition A shall have a substantially uniform grain size of 3 or finer, with occasional grains as large as 1 permissible, as determined by comparison of an etched specimen with the ASTM E 112 chart. In the case of a dispute, the Heyn's intercept method shall be used.

3.4.2 Condition B

3.4.2.1 Tensile test specimens, cut from the forging or cross-rolled plate and tested at the temperatures indicated in accordance with ASTM E 8, shall conform to the following requirements. Specimens to be tested at 1000°F shall be held at heat for 30 minutes prior to testing. Rate of strain for testing at 1000 ±10°F shall be maintained at approximately 0.005 inch per inch per minute to the 0.2 percent yield strength.

	R.T.	1000°F
Ultimate tensile strength, psi	175,000	160,000
Yield strength, (0.2 percent offset) psi	120,000	110,000
Elongation, percent in 4D	12.0	12.0
Reduction of area, percent	15.0	15.0

3.4.2.2 Condition B Stress-Rupture Properties: Specimens cut from forgings or cross-rolled plate shall be tested under the following conditions.

3.4.2.2.1 A smooth test specimen shall be maintained at 1500 ±5°F, under a continuously applied axial stress of 42,500 psi, and shall not rupture in less than 23 hours. The test shall be continued to rupture, and the elongation after rupture, measured at room temperature, shall be a minimum of 5 percent in 4D.

3.4.2.2.2 A combination smooth and notched test specimen, machined to the dimensions of Figure 1, shall be maintained at 1350 ±5°F under a continuously applied axial stress of 75,000 psi and shall not rupture in less than 23 hours. The test shall be continued to rupture. Failure of the smooth section shall not occur in less than 23 hours, but it shall fail in less time than the notched section. Elongation of the smooth section after rupture shall be a minimum of 5 percent in 4D, measured at room temperature.

3.4.2.2.3 Separate smooth and notched test specimens, machined from adjacent sections of the same piece with gauge sections conforming to the respective dimensions of Figure 1, may be tested as an alternate procedure, using the same test conditions. The smooth specimen shall not rupture in less than 23 hours, and elongation after rupture measured at room temperature shall be not less than 5 percent in 4D. The notched specimen need not be tested to rupture, but rupture shall not occur in less time than the smooth section.

3.4.2.2.4 The tests may be conducted at a higher stress level, but the stress shall not be increased while the test is in progress. Time to rupture and elongation requirements shall be as specified.

3.4.2.3 Hardness of the fully heat-treated material shall be Brinell 313 to 403.

3.4.2.4 Grain Size: Forgings and cross-rolled plate heat treated to meet the property requirements of Condition B shall have a substantially uniform grain size of 3 or finer, with occasional grains as large as 1 permissible, as determined by comparison of an etched specimen with the ASTM E 112 chart. In the case of a dispute, the Heyn's intercept method shall be used.

3.4.3 Condition C

3.4.3.1 Tensile test specimens, cut from the forging or cross-rolled plate and tested at the temperatures indicated in accordance with ASTM E 8, shall conform to the following requirements. Specimens to be tested at 1000 ±10°F shall be held at heat for 30 minutes prior to testing. Rate of strain for testing at 1000 ±10°F shall be maintained at approximately 0.005 inch per inch per minute to the 0.2 percent yield strength.

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	RT	1000°F
Ultimate tensile strength, psi	190,000	170,000
Yield strength, (0.2 percent offset) psi	140,000	125,000
Elongation, percent in 4D	10.0	11.0
Reduction of area, percent	13.0	12.0

3.4.3.2 Condition C Stress-Rupture Properties: Specimens cut from forgings or cross-rolled plate shall be tested under the following conditions.

3.4.3.2.1 A combination smooth and notched test specimen, machined to the dimensions of Figure 1, shall be maintained at 1200 ±5°F under a continuously applied axial stress of 95,000 psi and shall not rupture in less than 125 hours. The test shall be continued to rupture. Failure of the smooth section shall not occur in less than 125 hours, but it shall fail in less time than the notched section. Elongation of the smooth section after rupture shall be a minimum of 10 percent in 4D, measured at room temperature.

3.4.3.2.2 A combination smooth and notched test specimen, machined to the dimensions of Figure 1, shall be maintained at 1350 ±5°F under a continuously applied axial stress of 75,000 psi and shall not rupture in less than 23 hours. The test shall be continued to rupture. Failure of the smooth section shall not occur in less than 23 hours, but it shall fail in less time than the notched section. Elongation of the smooth section after rupture shall be a minimum of 5 percent in 4D, measured at room temperature.

3.4.3.2.3 Separate smooth and notched test specimens, machined from adjacent sections of the same piece with gauge sections conforming to the respective dimensions of Figure 1, may be tested as an alternate procedure to the above using the same test conditions. The smooth specimen shall not rupture in less than 23 or 125 hours, as applicable, and elongation after rupture measured at room temperature shall be not less than 5 or 10 percent in 4D, as applicable. The notched specimen need not be tested to rupture, but rupture shall not occur in less time than the smooth section.

3.4.3.2.4 The above stress-rupture tests may be conducted at a higher stress level, but the stress shall not be increased while the test is in progress. Time to rupture and elongation requirements shall be as specified above.

3.4.3.3 Hardness of the fully heat-treated material shall be Brinell 313 to 403.

3.4.3.4 Grain Size: Forgings and cross-rolled plate heat treated to meet the property requirements of Condition C shall have a substantially uniform grain size of 3 or finer, with occasional grains as large as 1 permissible, as determined by comparison of an etched specimen with the ASTM E 112 chart. In the case of a dispute, the Heyn's intercept method shall be used.

3.5 Forging Stock

3.5.1 When a sample of forging or cross-rolled plate stock is forged or rolled to a test coupon and heat treated, specimens taken from the coupon shall have properties conforming to the requirements specified.

3.5.2 If specimens taken from the forging or cross-rolled plate stock are heat treated and have properties conforming to the requirements specified, the test shall be accepted as equivalent to the test of a forged or rolled coupon.

4. PROCESS CONTROL

4.1 Forging and cross-rolled plate material shall be produced by vacuum induction melting followed by vacuum arc remelting.

4.1.1 Material for cross-rolled plate may be electro-slag remelted.

5. INSPECTION

5.1 Tolerances shall conform to the latest issue of AMS 2261 as applicable.

6. IDENTIFICATION AND PACKING

6.1 Forgings and cross-rolled plate shall be identified in accordance with MC5014.

7. APPROVAL OR PROCUREMENT

7.1 If necessary to make any change in equipment, procedures, and techniques after approval is granted, the source (forging or material) shall obtain permission from AiResearch Materials Engineering and Manufacturing Engineering prior to the first shipment incorporating such change.

8. REPORTS

8.1 The supplier of the material shall furnish with each shipment a report of chemical composition and test results on each heat to determine conformance to the technical requirements of this specification. This report shall include size of the original heat, the purchase order, material specification, heat number, forging or cross-rolled plate part number, and size of stock used to make the forgings or plate.

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MATERIAL SPECIFICATION	CODE IDENT NO. 99193	SPECIFICATION NO. EMS55388	REV LTR C

8.2 The supplier of finished or semi-finished parts shall furnish with each shipment a report showing the quantity, purchase order, materials specification, contractor or other direct supplier of material, and part number. When material for making parts is produced or purchased by the parts supplier, the supplier shall inspect each lot of material to determine conformance to the requirements of this specification, and shall include in his report a statement that the material conforms, or shall include the results of laboratory tests that determine conformance.

9. QUALITY CONTROL

9.1 The material shall be uniform in quality and condition, sound, and free from foreign materials and from internal and external imperfections detrimental to usage of the material.

9.2 Material not conforming to the requirements of this specification shall be rejected.

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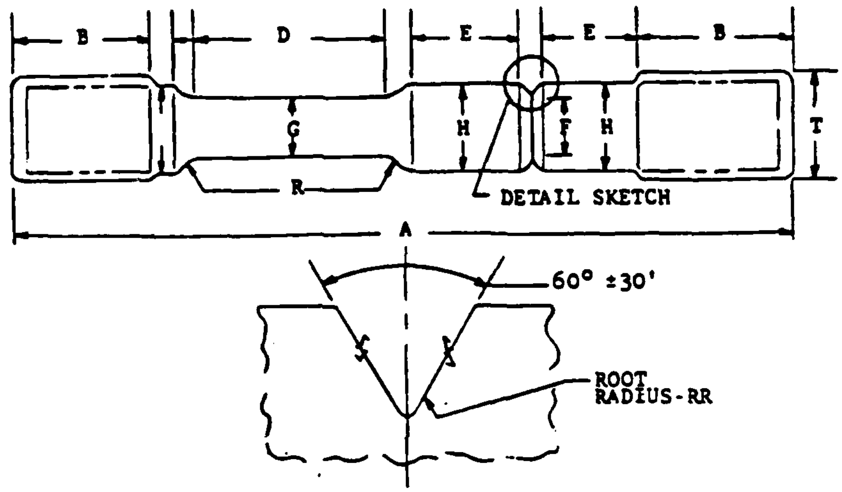

Specimen Number	Center Gage Diameter G, Inch	C	D, min	E, min	F	H	R, min	RR
1	0.160	1/8	0.65	3/8	0.160	0.226	0.125	0.005
2	0.178	1/8	0.75	3/8	0.178	0.250	0.125	0.005
3	0.252	1/8	1.0	3/8	0.252	0.375	0.125	0.007
Tolerance	±0.001	±1/16	--	--	±0.001	±0.003	--	±0.0005

Note 1. Finish the specimen to 8 or better on all "f" surfaces.
Note 2. The difference between dimensions "F" and "G" shall not exceed 0.0005 in. for specimens 1 and 2. The difference shall not exceed 0.001 in. for specimen 3.
Note 3. Taper gage length "D" to center so that diameter "G" at the ends of the gage length exceeds diameter "G" at the center of the gage length by 0.0005 - 0.0015 inch.
Note 4. All sections shall be concentric about the specimen axis within 0.001 inch.
Note 5. Thread size "T" shall be equal to or greater than "H".
Note 6. Dimensions "A" and "B" are not specified.

FIGURE 1

COMBINATION SMOOTH-AND-NOTCHED TEST SPECIMEN

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AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

SUBSTANTIATION TEST INSTRUCTION - FORGINGS

1. SCOPE

1.1 Purpose

This substantiation test instruction (STI) document establishes substantiation test requirements and procedures to establish and approve a source for a forging represented in a unit that requires qualification (military) or certification (civil, which includes commercial and industrial) tests.

Testing shall be performed for the following conditions:

(a) A change in the fixed process.
(b) The modification of part configuration.
(c) The addition of new sources.

NOTE: Testing for conditions (a) and (b) shall be accomplished only when it is established by the Engineering Project that the change or modification is significant enough to affect mechanical properties.

1.2 Definitions

Product-Line Category - A product-line category is the alphabetical designation for the originating Engineering Project. See Table I.

Test Class - A test class is the numerical designation for a specific test. See Section 3.

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TABLE I

PRODUCT-LINE ENGINEERING PROJECT CATEGORIES

Category	Engineering Project	Applicable Project Test Classes
A	Aircraft Propulsion Engines	1, 2, or 3
B	Gas Turbines (Non-Aircraft Propulsion)	1 through 10
C	Turbine Starters	1, 2, or 3
D	Air Motor Actuator Systems	1, 2, or 3
E	Control Systems	1, 2, or 3
F	Turbine Motors	1, 2, or 3

2. REQUIREMENTS

2.1 Source Selection Approval

Vendors must qualify as either a Trial or Approved Supplier in accordance with AiResearch Operational Procedure 4.90 before inspection of the vendor's forging is initiated.

2.2 Test Requirements and Acceptance Criteria

The following analyses and tests shall be conducted on a candidate forging or forgings as appropriate. Proposed alternate-source forgings used in substantiation tests shall be identical in materials, fabrication, processing, and all other respects with subsequent production forgings. No changes shall be made without AiResearch approval.

2.2.1 Chemical Analysis

Material certification by the vendor is required. When deemed necessary, a certified copy of the chemical analysis report from a source acceptable to AiResearch, to determine that the forging material(s comply with the specified materials, shall be furnished to AiResearch with the candidate forging.

2.2.2 Physical Analysis

Material certification by the vendor is required. When deemed necessary, a certified copy of the physical analysis report from a source acceptable to AiResearch, to determine that the forging complies with applicable data, shall be furnished to AiResearch with the candidate forging(s).

2.2.3 Engineering Samples

Prior to beginning a forging test program, at least one sample forging representative of the type to be tested that has undergone complete chemical and dimensional inspection, as appropriate, shall be submitted by the Quality Control Department to Engineering for a comprehensive process analysis and evaluation. A record of any deviations from the forging requirements on a First-Article Inspection Report shall accompany the sample.

2.3 Substantiation Data

2.3.1 Retention

Retention of substantiation test data shall be in accordance with the applicable operational procedure(s) in the AiResearch Operational Procedures Manual.

2.3.2 Data

Quality Control shall verify receipt of and shall check conformance with the following data, when applicable, except for chemical analysis, which shall be checked by the Chemical Laboratory as applicable.

(a) Material, chemical, and physical analysis reports or certifications, as applicable

(b) Heat-treat certification compliance, as applicable

(c) Plating certification compliance, as applicable

(d) Supplier process sheets, as applicable

(e) Zyglo report or magnetic-particle inspection report

(f) X-ray acceptability

(g) Vendor certificate of compliance

(h) Inspection layout report

(i) Measured-data sheet

(j) First-article inspection record

(k) Test reports (required class tests)

(l) Receiving reports

(m) Weld certification, as applicable

(n) Vendor drawing(s), as required

(o) Grain flow sample

2.4 Class Test Data

Test data shall be recorded on the appropriate data sheets. In addition, a test log similar to Data Sheet Form DS-3967, Qualification Test Log Form P5330, or Laboratory Data Sheet Form PS177A shall be used by the test technicians, where applicable, and shall be maintained for the complete test.

3. TEST CLASSES

3.1 Applicability

Test classes that follow in this section shall be applicable. Field evaluation in the end unit, acceptable to Engineering, may be substituted for test Class 1. Such evaluation must be appropriately documented and data retained as prescribed in Paragraph 2.3.1. AiResearch shall conduct the testing for these classes.

3.2 Test Class 1

The Engineering Project will determine if a forged part from an alternate vendor shall be subjected to a supplemental qualification test. They shall also specify the quality and magnitude of the test.

3.3 Test Class 2

Class 2 testing is to be conducted in accordance with the procedure in the following subparagraphs. This procedure may be modified by Engineering Project by issuing supplemental instructions.

3.3.1 Material Properties

(a) Turbine (Waspaloy) - A minimum of five forgings from each of a minimum of two master heats incorporating two heat-treat lots (10 forgings minimum) shall be destructively tested prior to fixed process approval. Testing shall consist of the following:

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(1) Two room-temperature tensiles per forging

(2) Two 1000°F tensiles per forging

(3) Two 1350°F stress-rupture per forging

(4) One 1500°F stress-rupture per forging

(5) Ten room-temperature and 10 elevated-temperature low-cycle fatigue specimens

NOTE: The location on the forging from which the test specimens are to be machined shall be established by Engineering for each configuration. Temperature for low-cycle fatigue testing shall be defined by Engineering.

(b) Turbine (Super Waspaloy) - A minimum of five forgings from each of a minimum of two master heats, incorporating two heat treat lots (10 forgings minimum), shall be destructively tested prior to fixed-process approval. Testing shall consist of the following:

(1) Two room-temperature tensiles per forging

(2) Four 1200°F tensiles per forging

(3) Two 1150°F stress-ruptures per forging

(4) Two 1250°F stress-ruptures per forging

(5) Ten room-temperature and six elevated-temperature low-cycle fatigue specimens

NOTE: The location on the forging from which the test specimens are to be machined and the exact test conditions shall be established by Engineering for each configuration. Temperature for low-cycle fatigue testing shall be defined by Engineering.

(c) Compressor - If a change in the fixed process or configuration is required with a current vendor, a minimum of two forgings from two master heats incorporating two heat-treat lots (four forgings minimum) shall be destructively tested prior to fixed-process or configuration-change approval.

MATERIAL SPECIFICATION	CODE IDENT NO 99193	SPECIFICATION NO. EMS 52406	REV LTR C

1. APPLICATION

1.1 This specification covers aircraft-quality forged parts produced by processes in which controlled plastic deformation under impact or pressure is used.

1.2 Forgings in accordance with this specification shall be classified as follows:

CLASS I (A) Rotating parts operating at temperatures in excess of 1000°F, such as integral turbine wheels, turbine disks, and exducers.

(B) Rotating parts operating at temperatures, from room temperature to 1000°F, such as integral compressor wheels, compressor wheel disks, inducers, impellers, and fans.

CLASS II Inserted blades, buckets, and vanes.

CLASS III Containment rings.

CLASS IV General application shafts, structural parts, housings, fittings, rings, and gears.

(A) Forging fixed process NOT required.

(B) Forging fixed process required.

CLASS V Forgings for cryogenic applications.

1.3 Forging class shall be specified when referencing this specification.

1.3.1 When Class IV is specified without a subclass of either "A" or "B", then Class IV A shall apply.

2. APPLICABLE DOCUMENTS

2.1 The following documents are applicable to the extent herein referenced.

2.1.1 <u>AiResearch Material Specification</u>

MC5014 Marking requirements

MATERIAL SPECIFICATION	CODE IDENT NO 99193	SPECIFICATION NO. EMS 52406	REV LTR B

3.6 **Heat Treatment** - Heat treatment shall be as specified. Only approved vendors shall be used for heat treating.

3.7 **Cleaning** - Forgings shall be furnished descaled. Titanium forgings shall not be cleaned by immersion in acid without the prior approval of AiResearch.

3.8 **Grain Flow** - Grain flow shall be as specified. Grain flow shall also show no evidence of the billet having been cocked when upsetting.

3.8.1 Displacement of the centerline of the billet, with respect to the centerline of the forging, shall not exceed one-tenth the outer diameter of the wheel, impeller, disk, and gear forgings, or shall not exceed 3/4 inch, whichever is the smallest.

3.8.2 No evidence of buckling of the billet shall be permissible.

4. PROCESS CONTROL

4.1 Class I forgings shall be forged from round or octagon billets. Round cornered square billets may be used only if a separate forging operation is used to shape the billet into a round or octagon.

4.1.1 Billets shall be prepared such that the ends are essentially parallel.

4.1.2 Initial upset shall be on end grain.

4.1.3 Where radial properties are necessary close to the center of upset type forgings, similar to Sketches 1B, 2B, 3B and 4B billets shall be forged tapered on the ends before performing the initial upsetting operation.

4.1.4 For Class I forgings, relief shall be provided in blocker and/or finish dies to center billets.

4.2 Figures 1 through 11 show typical forging configurations and grain flow patterns.

4.3 Figures 1 through 5 show disk, integral shaft, impeller and finger forgings applicable to Class I forgings.

4.4 Figure 6 shows typical grain flow pattern for shrouded and unshrouded blades representative of Class II forgings.

4.5 Figure 7 shows grainflow requirements for Class III containment rings.

4.5.1 Class III rings shall be manufactured by ring rolling or mandrel forging.

4.6 Figures 8 through 11 show typical configurations applicable to Class IV gear blanks.

4.7 Proposed forgings for Classes I and II or of an unusual or special size for other classes shall be coordinated with the applicable engineering groups, Manufacturing Engineering Group, and Materials Engineering.

5. INSPECTION

5.1 Inspection tests required shall be performed by the vendor or other AiResearch-approved source.

6. IDENTIFICATION AND PACKING

Forgings shall be identified in accordance with AiResearch Specification MC5014.

7. APPROVAL OR PROCUREMENT

7.1 Destructive Testing - The first representative part produced of a forged configuration shall be sectioned and tested to assure conformance with the applicable engineering requirements. Vendor shall not proceed with the production forgings for Classes I through III and V until test results on the destruct forging have been approved by AiResearch Materials Engineering.

7.2 Changes in Forging Procedure - The following shall be considered as changes in the forging procedure and shall be cause for re-evaluation of technical requirements in accordance with paragraph 7.1.

7.2.1 Changes in size or configuration of forging stock.

7.2.2 Significant changes in die configuration.

7.2.3 Changes in die sequence and heating and forging cycles.

7.2.4 Changes in heating temperatures and times.

7.2.5 Any change in the amount of final hot work reduction imparted to the forging following the last heating operation.

MATERIAL SPECIFICATION	CODE IDENT NO 99193	SPECIFICATION NO EMS 52406	REV LTR C

REPORTS

8.1 Forging Procedures - Forging vendors shall prepare a written forging procedure for Class I through Class III, and Class IV B forgings, and submit a copy to AiResearch for approval of the procedure with first-order shipments and prior to forging second-order parts. This forging procedure shall list in detail all operations and procedures used by the vendor in the manufacture of the forged parts, along with upper and lower control limits for these operations where applicable.

A forging procedure shall consist of, but shall not be limited to, the following items:

8.1.1 Forgings stock; size and weight. In addition, for rings, starting OD, thickness, and initial ID hole size.

8.1.2 Die lubricant.

8.1.3 Preheat furnace; identity, atmosphere, and temperature.

8.1.4 Forging equipment; identification, type, and size.

8.1.5 Initial furnace soak time and temperature range .

8.1.6 On-die temperature/off-die temperature for each forging cycle.

8.1.7 Number of blows, revolutions, and passes for each forging cycle, give range

8.1.8 Number of reheats required specific number , soak time range , and temperature range .

8.1.9 In-process conditioning, grinding, and inspections.

8.1.10 Heat-treat cycle, if required, including type of furnace, temperature, atmosphere, and time at temperature.

8.2 Once established and approved by AiResearch, the forging procedure shall be considered a "fixed process" and cannot be changed without prior approval from AiResearch. All

operational deviations from the "fixed process" shall be noted on the certified test report that accompanies each shipment of forgings. Variations from the "fixed process"--i.e., changes in heating times, temperature, forging sequence, etc.--shall be submitted to AiResearch on an RMRA form, Request for Material Review Action, for disposition of the forgings involved.

MATERIAL SPECIFICATION	CODE IDENT NO 99193	SPECIFICATION NO. EMS 52406	REV LTR A

8.2 (Contd.) Operations and processes considered proprietary by the forging vendor may be listed on a master copy of the "fixed process" which is kept in the vendor's file; however, the range of control for such operations must be shown on the copy of the "fixed process" submitted to AiResearch with the parts.

8.3 The forging vendor shall furnish with each shipment three copies of a report showing the purchase order number, part number, material specification, heat or lot number, size of stock used, quantity of parts, and the results of applicable tests for chemical composition, mechanical properties, grain size, grain flow, and hardenability.

9. QUALITY CONTROL

9.1 Forging stock shall be clean, sound, and free of imperfections detrimental to the fabrication and/or performance of the parts and subject to the applicable inspection requirements for aircraft-quality material. Forging stock shall be air- or vacuum-melt material as required by the applicable materials specification.

9.2 Process controls applicable to forgings produced under this specification shall be audited by the vendor's Quality Control Department, group, or representative on a monthly basis, and reports of this audit shall be made available for review.

9.3 Vendors shall keep records of conformance to all control items in a fixed process for a period of four years after date of shipment.

In the case of parts requiring traceability, the above records shall be kept for a period of seven years after date of shipment.

9.4 Forged parts not conforming to this specification shall be rejected.

MATERIAL SPECIFICATION	90193	EMS 52406	B

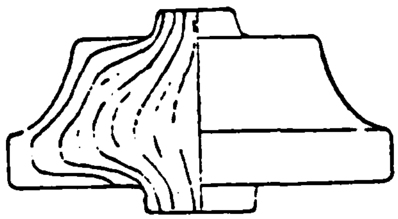


FIGURE 4 A

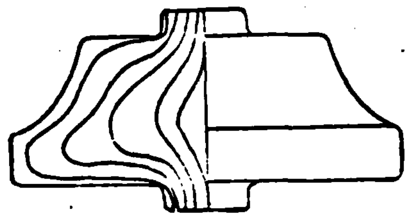


FIGURE 4 B

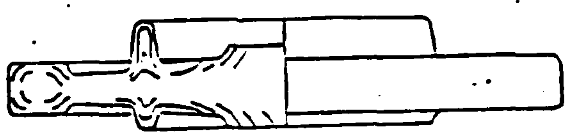


FIGURE 5

APPENDIX C

```
BEGIN

C MAIN PROGRAM
C THIS IS THE MAIN PROGRAM FOR
CDETERMINING QUALITY CHARTS FOR
CARC CO.
C CASTINGS AND FORGINGS. IT IS TO
CBE USED IN CONJUNCTION
C WITH THE SUBROUTINES SPECIFIED
CIN THE APPROPRIATE MANUAL.

COMMON/UINPUT/LR,LW,FMT(19),TITLE(19),
PNUM(19),FMT2(19)
COMMON/STAT1/SORTOT,STOT,XBAR,INCI
COMMON/STAT2/X(10),NSER(403),SSDEV,COMP(
05,5),VALE(11,400)
COMMON/PLOT1/UCL,RCL,RBAR,UCLL,RCLL,THIN,
N
COMMON/VALUE1/LABEL(11),DIVL,SP1(4)
DIMENSION C3(10),C4(10),A2(10),RANGE(403)
,SUBAR(403),CC2(10),CC3(10)

C THE FOLLOWING DATA STATEMENTS
CCONTAIN VALUES FOR C3, C4, AND
CA2 FOR
C FINDING THE APPROPRIATE CONTROL
CLIMITS USING STANDARD TERMINOLOG
C.
C IF ANOTHER METHOD OF DETERMININ
C THESE LIMITS (OTHER THAT 3
CSIGMA)
C THE DATA MAY BE CHANGED, VALUES
CFOR THE LIMITS MAY BE INPUTTED,
COR
C A DIFFERENT CALCULATION METHOD
CMAY BE INCLUDED IN THE PROGRAM!!
C'

DATA C3/0.0,0.0,0.0,0.0,0.0,0.0,0.0,.09,.14,.
18,.22/,C4/0,0,3.27,2.57,2.28,2.11,2.00,
1.92,1.86,1.82,1.78/,A2/0.0,1.88,1.02,.
73,.59,.49,.42,.37,.34,.31/,CC2/1.0,1.13,
1.69,2.06,2.33,2.53,2.70,2.85,2.97,3.08/,
CC3/.99,.95,.99,.90,.96,.95,.93,.82,.91,.
90/

C NG = NUMBER OF SUBGROUPS
C N = NUMBER OF ELEMENTS IN THE
CSUBGROUP
C ISKIP = MEANS OF SUPPRESSING
CPRINTING OF MEANS AND RANGES (0)
C INLIP = U), IF USER WISHES TO
CSPECIFY THE MEANS AND CONTROL
CLIMITS

LR=5
LW=6
```

APPENDIX C

```
C...101
    READ(LR,15)TITLE
    READ(LR,15)PNUP
    WRITE(LW,16)TITLE
    WRITE(LW,35)PNUP
    |---C 15 FORMAT(19A4)
    |   C 16 FORMAT(1H1,19A4)
    READ(LR,20)NG,N,ISKIP,INLIP,IPLOT
    |---C 20 FORMAT(I3,4I2)
    WRITE(LW,25)NG,N,ISKIP,INLIN,IPLOT
    |---C 25 FORMAT(1H0,I3,5X,I2,5X,I2,5X
    |   CI2,5X,I2)
    IF(N.EQ.0) GO TO 100          TRUE
    FALSE
    |---C FMT=FORMAT SPECIFICATION AS
    |   CINPUT BY THE USER
    READ(LR,30)FMT
    |---C 30 FORMAT(19A4)
    WRITE(LW,35)FMT
    |---C 35 FORMAT(1H0,19A4)
    |---C THE FOLLOWING FOUR STATEMENTS
    |   CDETERMINE VALUES FOR THE VALUE
    |   C PLOT IN THE EVENT THERE ARE
    |   CMEASUREMENTS FROM MULTIPLE
    |   C LOCATIONS ON THE CASTING OR
    |   CFORGING..
```

```
IF(N.EQ.1)GO TO 36                    TRUE
        FALSE
READ(LR,15)FMT2
WRITE(LW,35)FMT2
READ(LR,FMT2)(LABEL(I),I=1,N)
WRITE(LW,39)(LABEL(I),I=1,N)
C   36
READ(LR,37)TPIR
---C 37 FORMAT(F10.3)
WRITE(LW,40)
---C 39 FORMAT(1HO,8A8)
   C 40 FORMAT('0','SERIAL #',20X,'
   CINPUT DATA BY POSITION')
SQRTOT = 0.0
STOT = 0.0
INCI = 0
---C THE FOLLOWING STATEMENTS
   CINITIALIZE THE HOLE ARRAY
DO 42 J=1,400
DO 41 I=1,11
C   41
HOLE(I,J) = 0.0
```

```
C   42)
CONTINUE

---C SUBROUTINE ASTATS IS NOW CALLED
   CTO DETERMINE SUBGROUP AVERAGES
   CAND
   C MEANS, THE POPULATION MEAN ,
   CAND THE POPULATION STANDARD
   CDEVIATION.

C   43)
CALL ASTATS (RANGE,SUBAR,NR,N)

WRITE(LW,44)XBAR,SSDEV,STOT,SQRTOT

---C 44 FORMAT(1HO,'THE MEAN =',F10.
   C2,5X,'STAND DEV =',F10.2,5X,'SUM
   C=',F1 10.2,5X,'SUM OF SQUARES ='
   CF10.2)

IF(N.EQ.1)GO TO 66          TRUE
      FALSE

IF(IMET.EQ.2)GO TO 45       TRUE
      FALSE

CALL ANALVR(N,NR)

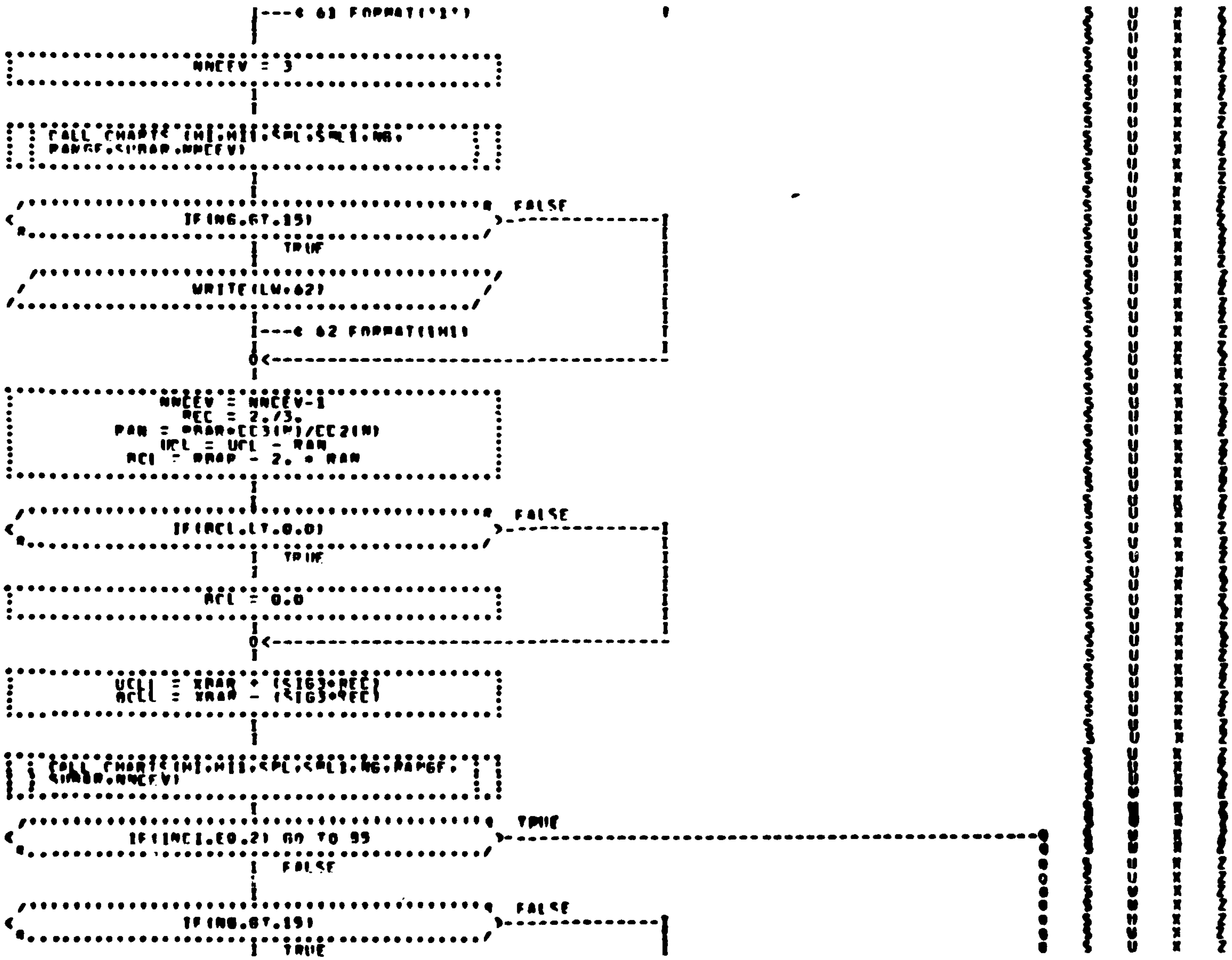
---C NOW A SORT IS PERFORMED TO
   CDETERMINE THE LARGEST RANGE AND
   CSUBGROUP
   C MEAN FOR SCALING USE.

C   45)
SML = 9.9E10
HI =-9.9E10
SPL1=SPL
HI1 =HI

CALL SORTS(SML,HI,RANGE,NR)

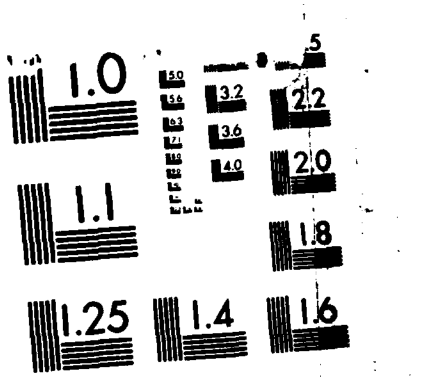
CALL SORTS(SML1,HI1,SUBAR,NR)
```

```
|---C NOW CALCULATE RBAR                        !
|
SUMR = 0.0
|
A------------> DO 50 I=1,NR
A              |
A     C    501 |
A              |
-------------- SUMR = SUMR + RANGE(I)
|
R = NG
RBAR = SUMR/R
|
|---C NOW CALCULATE LIMITS FOR                  !
    CRCHARTS                                    !
|
UCL = D4(N)*RBAR
RCL = D3(N)*RBAR
|
|---C NOW CALCULATE LIMITS FOR XBAR             !
    CCHARTS                                     !
|
SIG3 = A2(N)*RBAR
UCLL= XBAR + SIG3
RCLL= XBAR - SIG3
|
|---C REPLACE CONTROL LIMIT VALUES IF!
    CUSER DESIRES TO INPUT THEM.                !
|
< IF(INLIP.EQ.1) >  FALSE ---------------------|
|  TRUE                                         |
/ READ(LR,60)UCL,RBAR,UCL,RCLL,XBAR,UCLL /      |
|                                               |
|---C 60 FORMAT(6F10.0)                         |
|---C THE FOLLOWING STATEMENTS CALL             |
    SUBROUTINE CHARTS FOR PRODUCTION            |
    OF                                          |
    C THE DESIRED CONTROL CHARTS.               |
0<----------------------------------------------|
|
/ WRITE(LW,61) /
|
```

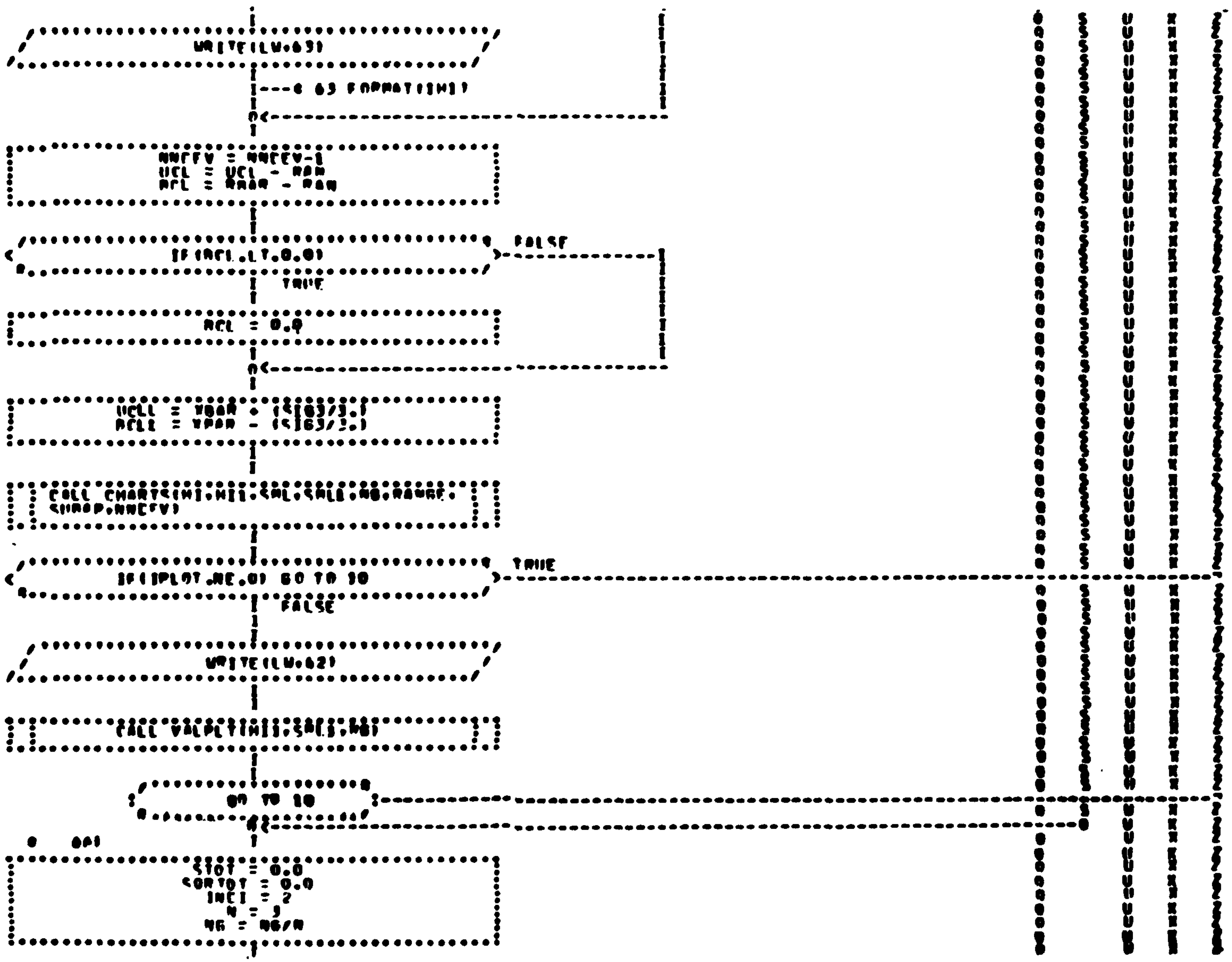

C 61 FORMAT('1')
NNCEV = 3
CALL CHART5 (MI,MII,SPL,SPL1,NG,
RANGE,SUMRAR,NNCEV)
IF(NG.GT.15)
FALSE
TRUE
WRITE(LW,62)
C 62 FORMAT(1H1)
NNCEV = NNCEV-1
REC = 2./3.
RAN = RRAR*CC3(M)/CC2(N)
UCL = UCL - RAN
RCL = RRAR - 2. * RAN
IF(RCL.LT.0.0)
FALSE
TRUE
RCL = 0.0
UCL1 = XRAR + (SIG3*REC)
RCL1 = XRAR - (SIG3*REC)
CALL CHART5(MI,MII,SPL,SPL1,NG,RANGE,
SUMRAR,NNCEV)
IF(INCI.EQ.2) GO TO 55
TRUE
FALSE
IF(NG.GT.15)
FALSE
TRUE

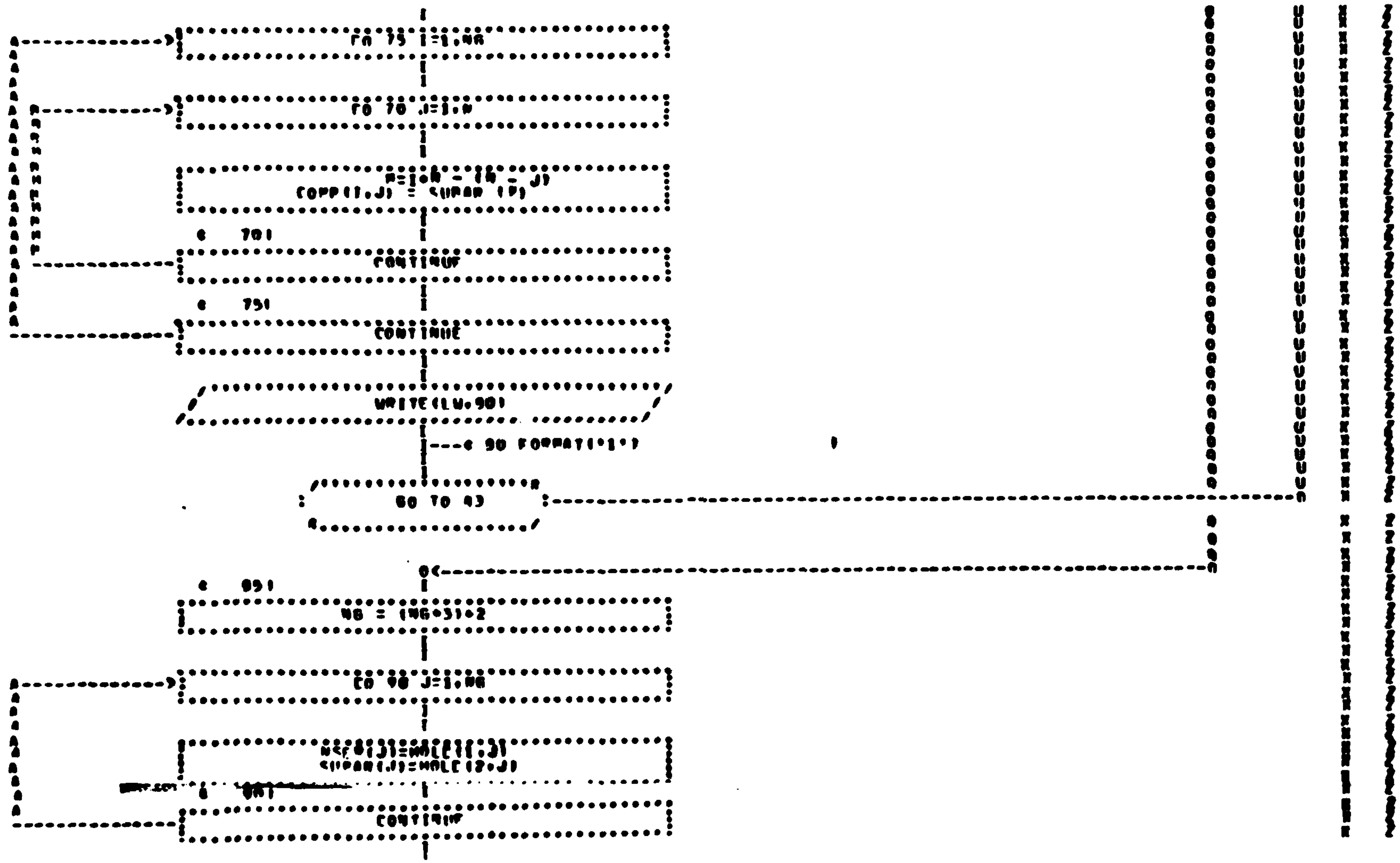
AD-A166 418 AN APPLICATION OF QUALITY CONTROL THEORY TO VENDOR-SUPPLIED PARTS AT AN A.. (U) AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OH D E GELLENBECK AUG 85 3/3

UNCLASSIFIED AFIT/CI/NR-86-13T F/G 5/1 NL

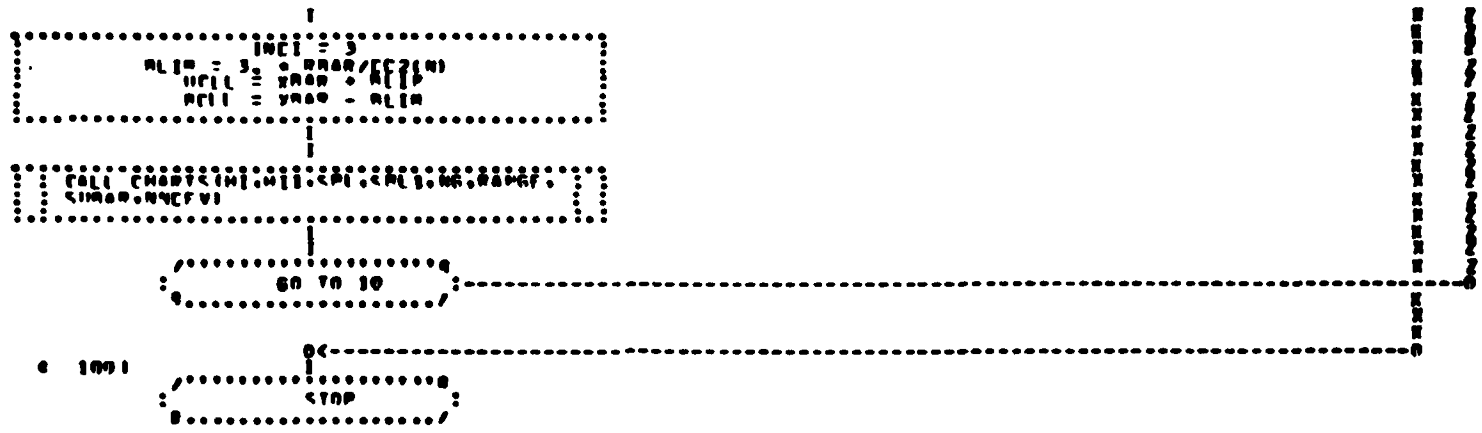


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A


WRITE(LW,63)
6 63 FORMAT(1H1)
NNCEV = NNCEV-1
UCL = UCL - RAN
RCL = RBAR - RAN
IF(RCL.LT.0.0)
FALSE
TRUE
RCL = 0.0
UCLL = YBAR + (S(63)/3.)
RCLL = YBAR - (S(63)/3.)
CALL CHARTS(HI,HII,SAL,SALE,NG,RANGE,
SUMAP,NNCEV)
IF(IPLOT.NE.0) GO TO 10
TRUE
FALSE
WRITE(LW,62)
CALL VALPLT(HII,SALE,NG)
GO TO 10
STOT = 0.0
SQRTOT = 0.0
INCI = 2
N = 3
NG = NG/N



CONTINUE
WRITE(LW,90)
90 FORMAT('1')
GO TO 43


INCI = 3
ALIM = 3. * XBAR/CC2(N)
UCLL = XBAR + ALIM
LCLL = XBAR - ALIM
CALL CHARTS(NI,NII,SPL,SPL1,NG,RANGE,
SIGMA,NYCEV)
GO TO 10
C 1001
STOP

```
SUBROUTINE CHARTS (NI,NI1,SPL,SPL1,
NG,RANGE,SUMAR,NNCEV)

C THIS SUBROUTINE WILL PRODUCE X-
C BAR AND RANGE CHARTS FOR THE
C INPUT DATA. USE CAUTION WHEN
C SPECIFYING!!!

COMMON/UINPUT/IR,LW,FMT(19),TITLE(19),
PNUM(19),FMT2(19)
COMMON/STAT1/SUMTOT,STOT,XBAR,INCI
COMMON/STAT2/ X(100),MSER(403),SSDEV,COMP(
99,5),MOLC(11,900)
COMMON/PLOT1/UCL,RCL,RBAR,UCLL,RCLL,IMIN,
N
COMMON/VALUE1/LABEL(11),CIV1,SP1(8)
DIMENSION SALE(403),IVECTR(37),IVECTY(
37),XALFX(403),RANGE(403),SUMAR(403),SP2(
8),R(403)
DATA IBLANK/' '/,IPOINT/'*'/,IONE/'1'/,
IDASH/'-'/,BLANK/' '/,IAST/'*'/,IP/'P'/

WRITE(LW,90)TITLE

WRITE(LW,91)PNUM

C 91 FORMAT('0','PART NUMBER: ',
C 19A4)

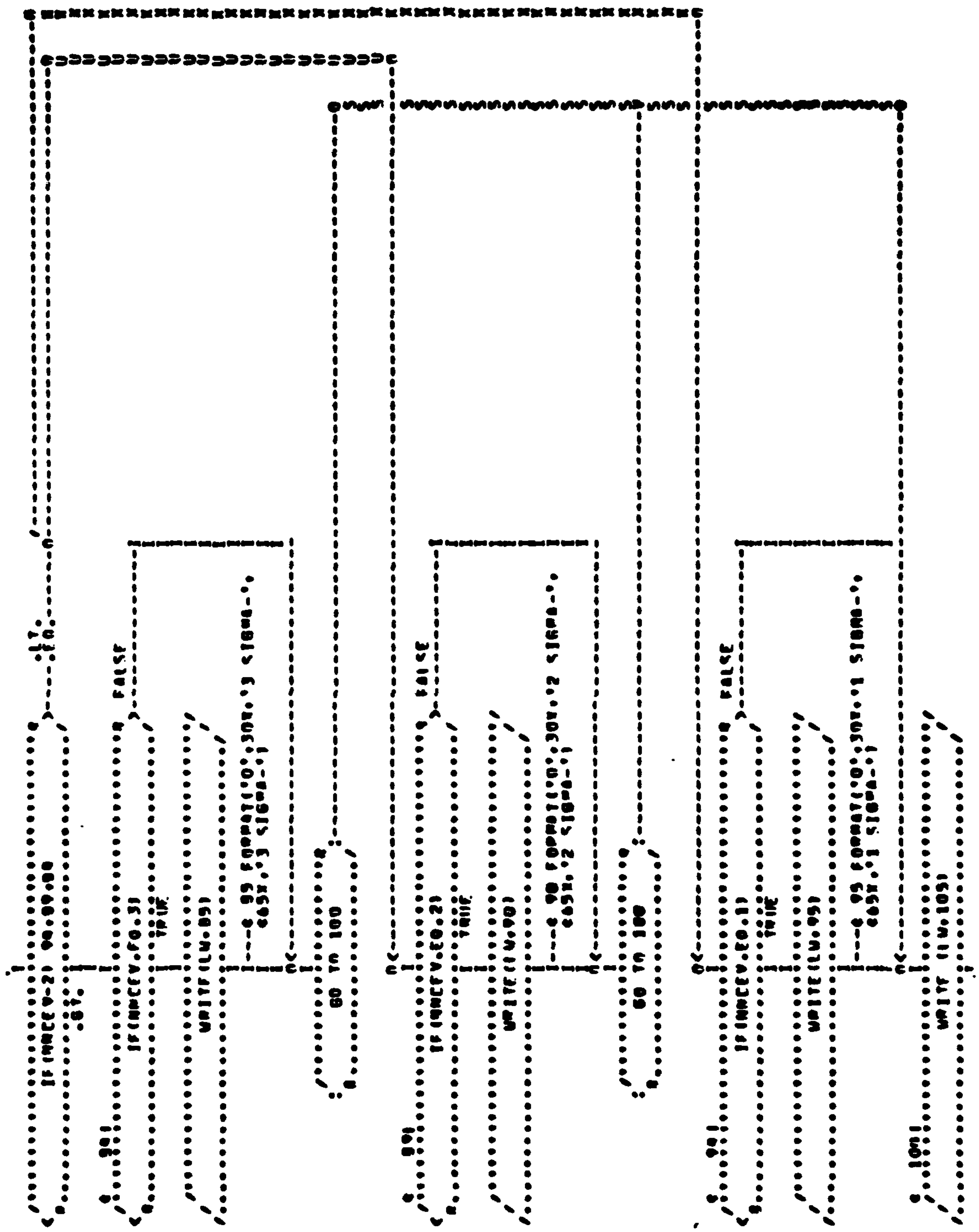
IF(INPT.EQ.3)GO TO 299          TRUE
FALSE

C 90 FORMAT(1H0,//,19A4)

IF(INCI.EQ.2)          FALSE
TRUE

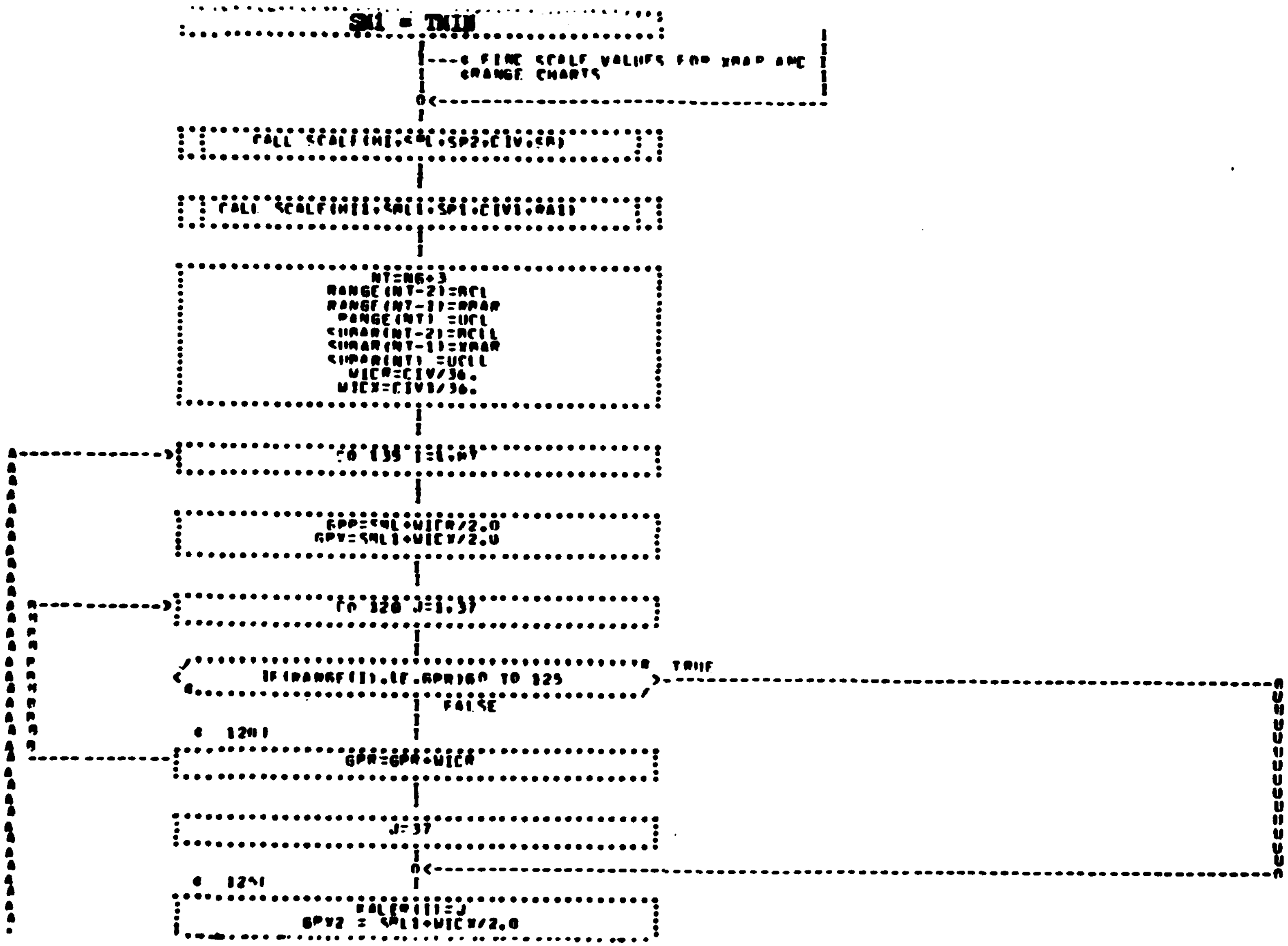
WRITE(LW,93)M

C 93 FORMAT('0','CHARTS FOR
C GROUPS OF ',I2,' CASTINGS/
C SAMPLINGS')
```

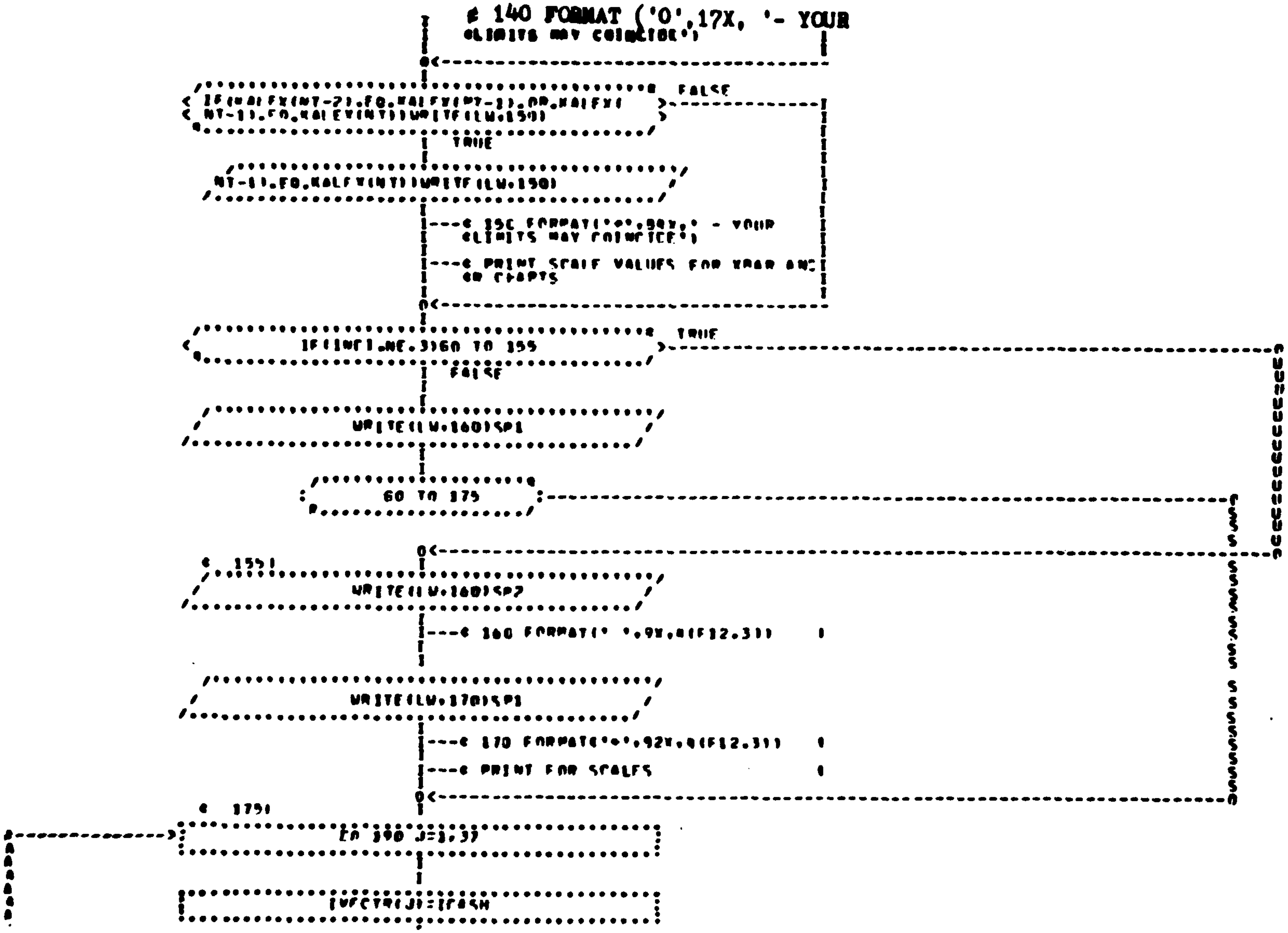

.LT.
.EQ.
.GT.
FALSE
TRUE
GO TO 100
FALSE
TRUE
GO TO 100
FALSE
TRUE

105 FORMAT(1H ,29X, 'RANGE CHART

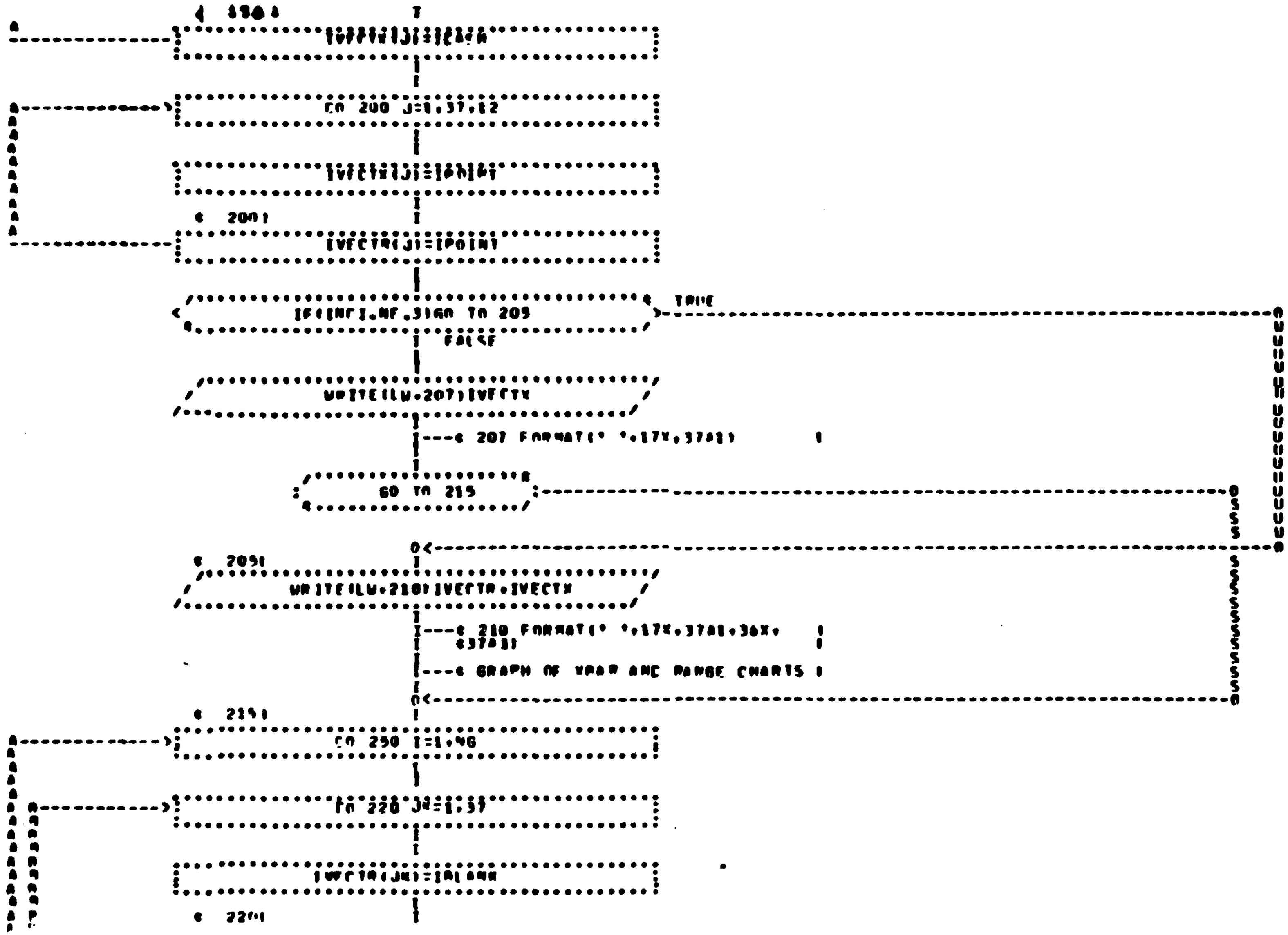
```
        I    &,62X,'X-BAR CHARTS'//)
        I
        I
   /WRITE (LU,110) RCL,RCLL,RBAR,XBAR,UCL,/
  / UCLL                                /
 /......................................
        I
        I---C 110 FORMAT(' ',17X,'LCL=',F10.4
        I    &59X,'LCL=',F10.4/ 13X,'CENTER='
        I    &F10.4,17X,'SERIAL',33X,'CENTER='
        I    &F10.4/39X,'UCL=', 2F10.4,13X,
        I    &NUMBER,09X,'UCL=',F10.4//)
        I
        0<----------------------------------------------
        I
  C 1351
 <      IF (UCL.GT.HI)                 >  FALSE
        I TRUE
        HI=UCL
        0<------------
 <      IF (UCLL.GT.HII)               >  FALSE
        I TRUE
        HII=UCLL
        0<------------
 <      IF (RCL.LT.SML)                >  FALSE
        I TRUE
        SML=RCL
        0<------------
 <      IF (RCLL.LT.SMLL)              >  FALSE
        I TRUE
        SMLL=RCLL
        0<------------
 <      IF (TMIN.LT.RCLL)              >  FALSE
        I TRUE
        I
```


SM1 = TRIM
---$ FINE SCALE VALUES FOR XBAR AND RANGE CHARTS
CALL SCALF(HI,SML,SP2,CIV,SR)
CALL SCALF(HI1,SML1,SP1,CIV1,RA1)
NT=NG+3
RANGE(NT-2)=RCL
RANGE(NT-1)=RBAR
RANGE(NT) =UCL
SUBAR(NT-2)=RCLL
SUBAR(NT-1)=XBAR
SUBAR(NT) =UCLL
WICR=CIV/36.
WICX=CIV1/36.
DO 135 I=1,NT
GPR=SML+WICR/2.0
GPX=SML1+WICX/2.0
DO 120 J=1,37
IF(RANGE(I).LE.GPR)GO TO 125
TRUE
FALSE
@ 120
GPR=GPR+WICR
J=37
@ 125
VALR(I)=J
GPX2 = SML1+WICX/2.0

```
DO 126 J=1,37
IF(TRIP.LE.GPY2) GO TO 127          TRUE
FALSE
C 126)
GPY2 = GPY2+WIDY
J=1
C 127)
N(I) = J
DO 130 J=1,37
IF(SUMAR(J).LE.GPY)GO TO 135        TRUE
FALSE
C 130)
GPY=GPY+WIDY
J=37
C 135)
NALFY(I)=J
C LOGIC FOR COINCIDING LIMITS
IF(NALFR(NT-2).EQ.NALFR(NT-1).OR.NALFR(
NT-1).EQ.NALFR(NT))WRITE(LW,100)    FALSE
TRUE
NT-1).EQ.NALFR(NT))WRITE(LW,100)
```



140 FORMAT ('0',17X, '- YOUR
ULIMITS MAY COINCIDE')
FALSE
IF(HALFX(NT-2).EQ.HALFX(NT-1).OR.HALFX(
NT-1).EQ.HALFX(NT))WRITE(LW,150)
TRUE
NT-1).EQ.HALFX(NT))WRITE(LW,150)
150 FORMAT('0',80X,' - YOUR
ULIMITS MAY COINCIDE')
PRINT SCALE VALUES FOR XBAR AND
R CHARTS
TRUE
IF(INFI.NE.3)GO TO 155
FALSE
WRITE(LW,160)SP1
GO TO 175
155)
WRITE(LW,160)SP2
160 FORMAT(' ',9X,8(F12.3))
WRITE(LW,170)SP1
170 FORMAT('+',92X,8(F12.3))
PRINT FOR SCALES
175)
DO 190 J=1,37
IVECTR(J)=ICASH


C 190
DO 200 J=1,37,12
C 200
IVECTR(J)=IPOINT
IF(INFI.NE.3)GO TO 205
TRUE
FALSE
WRITE(LU,207)IVECTX
C 207 FORMAT(' ',17X,37A1)
GO TO 215
C 205
WRITE(LU,210)IVECTR,IVECTX
C 210 FORMAT(' ',17X,37A1,36X,
C37A1)
C GRAPH OF YEAR AND RANGE CHARTS
C 215
DO 250 I=1,NG
DO 220 JJ=1,37
IVECTR(JJ)=IBLANK
C 220

```
IVECTX (JK)= IBLANK

IVECTR(KALFR(NT))=IONE
IVECTR(KALER(NT-2))=IONE
IVECTR(KALER(NT-1))=IONE
IVECTY(KALEY(NT-2))=IONE
IVECTY(KALEX(NT-1))=IONE
IVECTY(KALFY(NT))=IONE
IVECTY(M(I)) = IM
IVECTR(KALER(I))=IAST
IVECTY(KALEX(I))=IAST

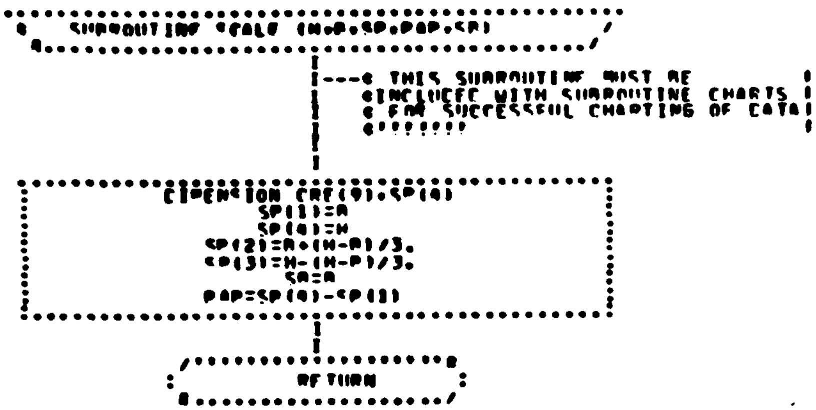
---C THE GRAPHING OF SUBGROUPS TAKES
   CPLACE NOW!!!!!!

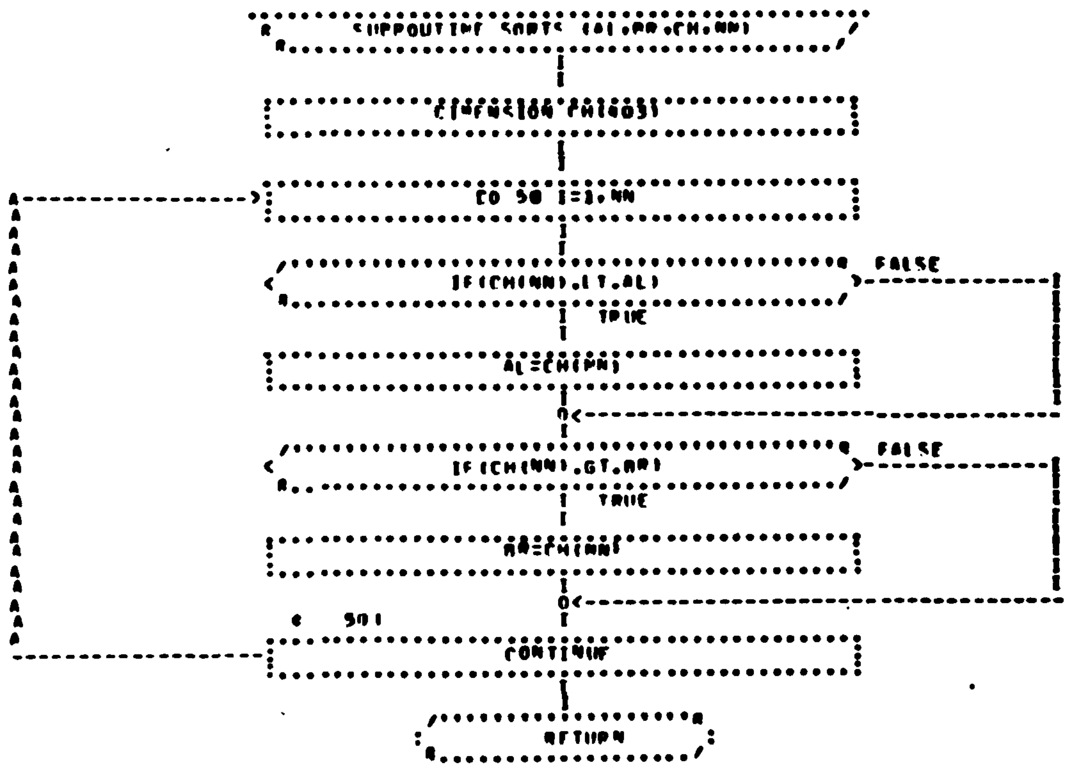
IF(INCI.EQ.3)GO TO 245                TRUE
FALSE
IF(ISKIP.NE.0) GO TO 280              TRUE
FALSE
WRITE(LW,230)RANGE(I),IVECTR,NSEP(I),
SUBAR(I),IVECTX
---C 230 FORMAT(' ',F12.3,5X,37A1,
   C10X,I5,5X,F12.3,4X,37A1)
GO TO 250
C 280)
WRITE(LW,210)IVECTR,IVECTX
C 245)
IF(ISKIP.NE.0)GO TO 247               TRUE
FALSE
WRITE(LW,246)SUBAR(I),IVECTX,NSEP(I)
---C 246 FORMAT(' ',F12.3,5X,37A1,
   C10X,I5)
```

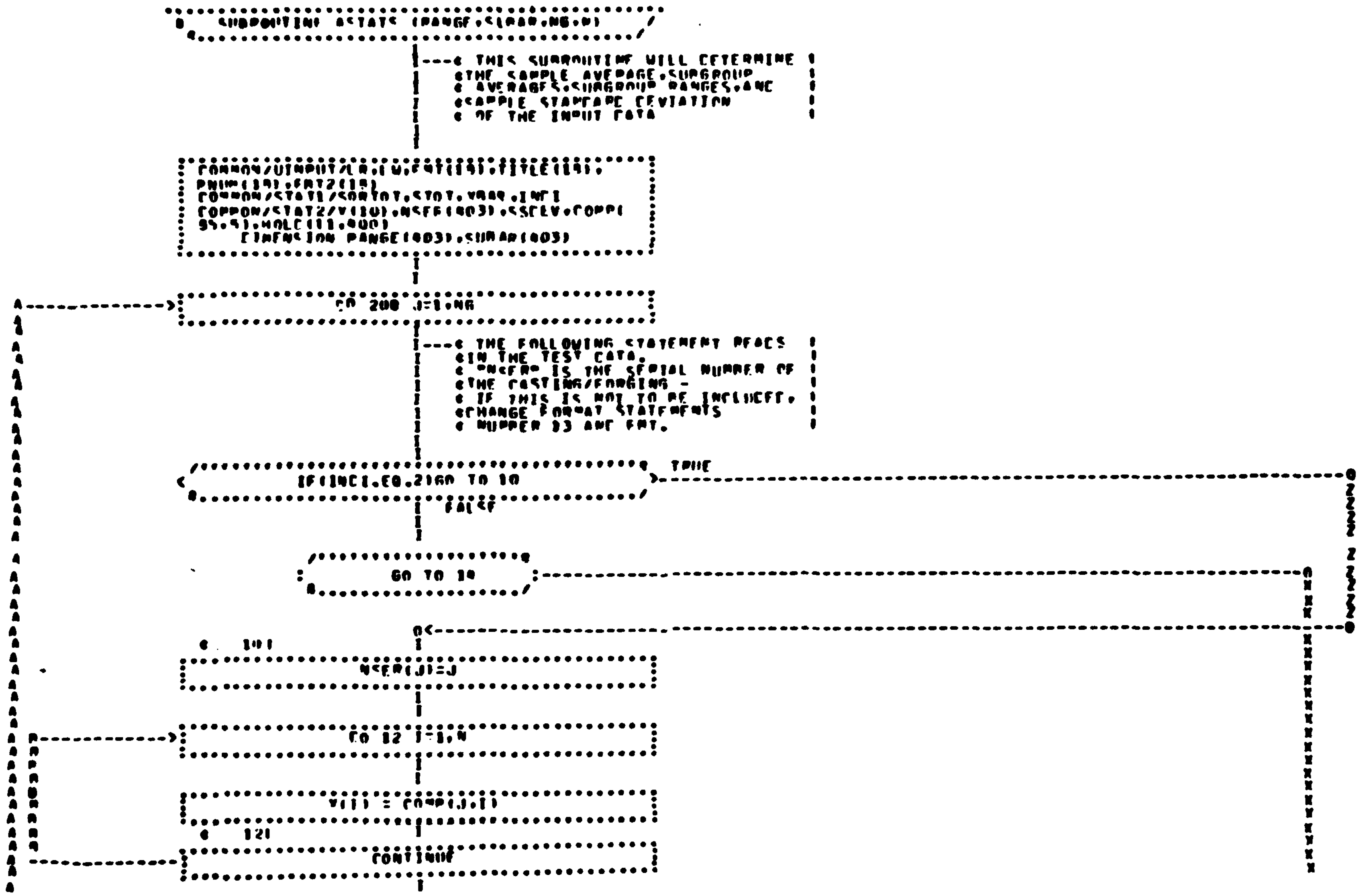
```
GO TO 250

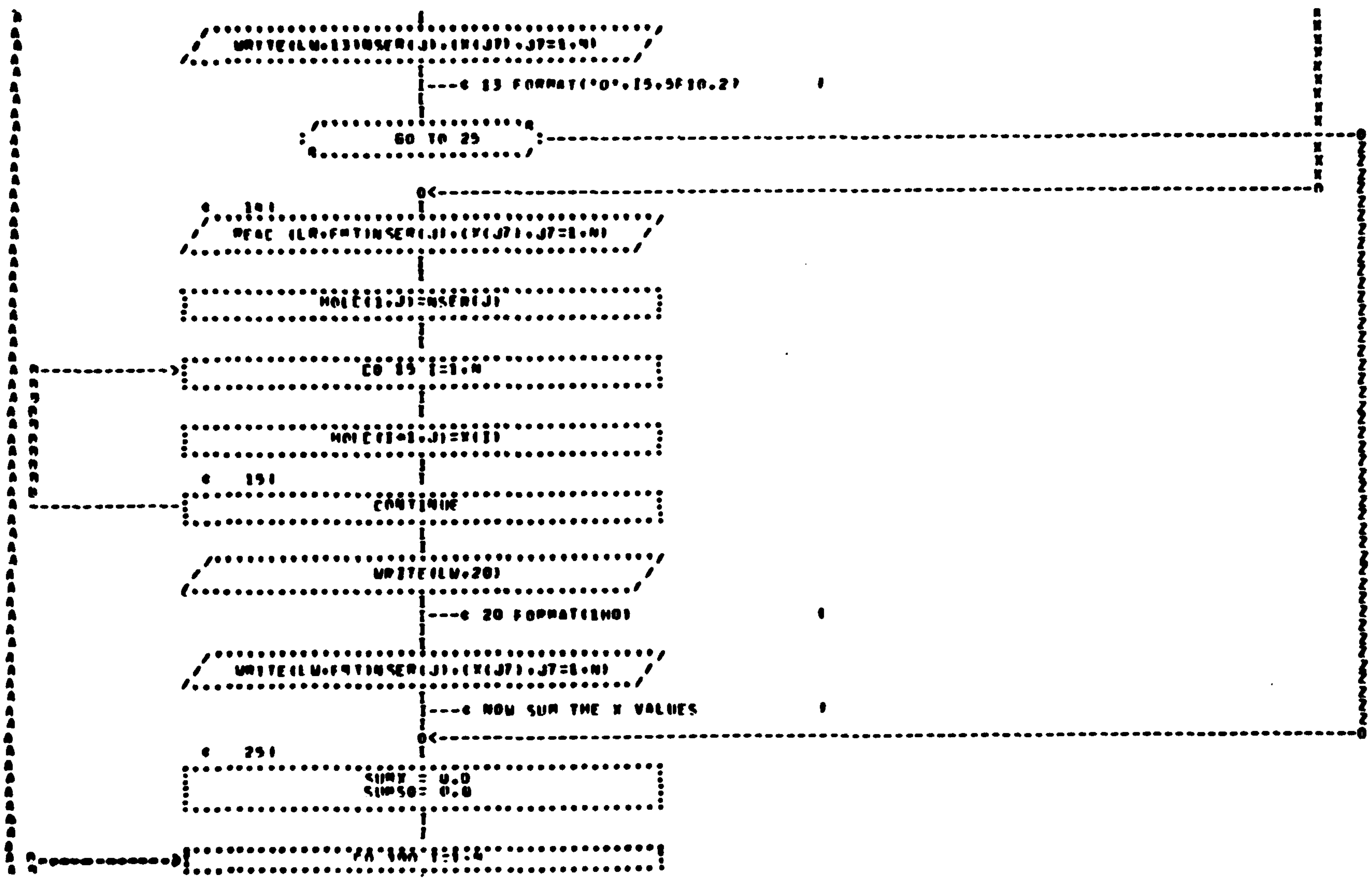
247 WRITE(LW,249)IVECTX,NSER(I)
    249 FORMAT(' ',17X,37A1,10X,I5)
250 CONTINUE
RETURN

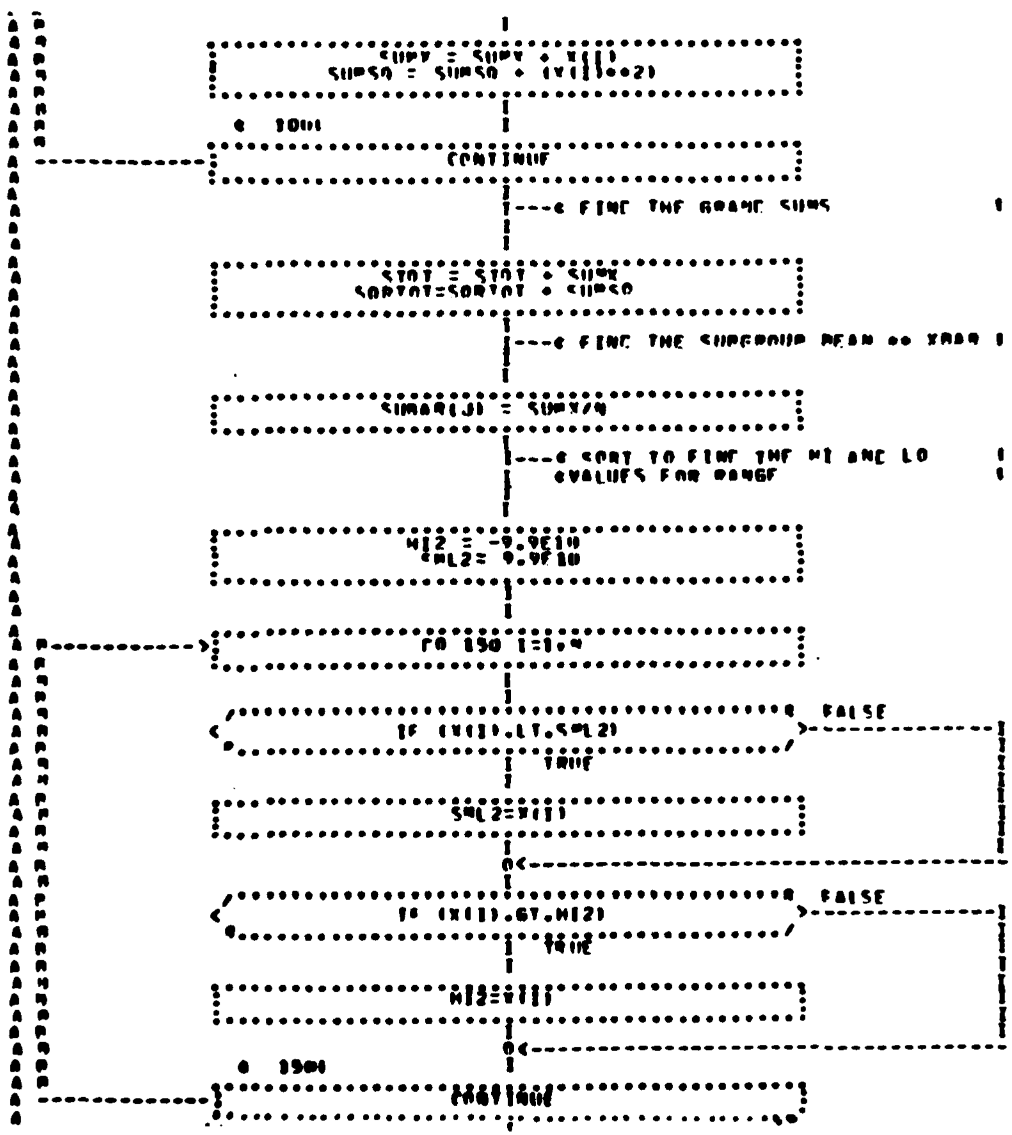
299 WRITE(LW,300)
    300 FORMAT('0',30X,'INDIVIDUAL
    &VALUE'/34X,'X CHART')
WRITE(LW,310)RCLL,XBAR,UCLL
    310 FORMAT(' ',17X,'LCL=',F10.4,
    &30X,'CENTER=',F10.4,17X,'I'
    &SERIAL'/39X,'UCL=',F10.4,13X,
    &NUMBER//)
GO TO 115
```


SUBROUTINE SCALE (H,B,SP,RAP,SA)
THIS SUBROUTINE MUST BE INCLUDED WITH SUBROUTINE CHARTS FOR SUCCESSFUL CHARTING OF DATA
DIMENSION CRE(9),SP(4)
SP(1)=B
SP(4)=H
SP(2)=B+(H-B)/3.
SP(3)=H-(H-B)/3.
SA=B
RAP=SP(4)-SP(1)
RETURN


SUBROUTINE SORTS (AL,AR,CH,NN)
DIMENSION CH(403)
DO 50 I=1,NN
IF(CH(NN).LT.AL)
FALSE
TRUE
AL=CH(NN)
IF(CH(NN).GT.AR)
FALSE
TRUE
AR=CH(NN)
50
CONTINUE
RETURN


SUBROUTINE ASTATS (RANGE,SUBAR,NG,N)
C THIS SUBROUTINE WILL DETERMINE
C THE SAMPLE AVERAGE,SUBGROUP
C AVERAGES,SUBGROUP RANGES,AND
C SAMPLE STANDARD DEVIATION
C OF THE INPUT DATA
COMMON/UINPUT/LR,LW,FMT(15),TITLE(15),
PNUM(15),FMT2(15)
COMMON/STAT1/SORTOT,STOT,VBAR,INCI
COMMON/STAT2/Y(100),NSER(803),SSDEV,COMP(
95,5),HOLD(11,800)
DIMENSION RANGE(803),SUBAR(803)
DO 200 J=1,NG
C THE FOLLOWING STATEMENT READS
C IN THE TEST DATA.
C "NSER" IS THE SERIAL NUMBER OF
C THE CASTING/FORGING -
C IF THIS IS NOT TO BE INCLUDED,
C CHANGE FORMAT STATEMENTS
C NUMBER 33 AND FMT.
IF(INCI.EQ.2)GO TO 10
TRUE
FALSE
GO TO 10
101
NSER(J)=J
DO 12 I=1,N
Y(I) = COMP(J,I)
121
CONTINUE


WRITE(LW,13)NSER(J),(X(J7),J7=1,N)
C 13 FORMAT('0',I5,5F10.2)
GO TO 25
C 10
READ (LR,FMT)NSER(J),(Y(J7),J7=1,N)
HOLE(1,J)=NSER(J)
DO 15 I=1,N
HOLE(I+1,J)=X(I)
C 15
CONTINUE
WRITE(LW,20)
C 20 FORMAT(1H0)
WRITE(LW,FMT)NSER(J),(X(J7),J7=1,N)
C NOW SUM THE X VALUES
C 25
SUMX = 0.0
SUMSQ= 0.0


SUMX = SUMX + X(I)
SUMSQ = SUMSQ + (X(I)**2)
@ 100
CONTINUE
C FIND THE GRAND SUMS
STOT = STOT + SUMX
SQRTOT=SQRTOT + SUMSQ
C FIND THE SUBGROUP MEAN ** XBAR
SUMAR(J) = SUMX/N
C SORT TO FIND THE HI AND LO
VALUES FOR RANGE
HI2 = -9.9E10
SML2= 9.9E10
DO 150 I=1,N
IF (X(I).LT.SML2)
FALSE
TRUE
SML2=X(I)
IF (X(I).GT.HI2)
FALSE
TRUE
HI2=X(I)
@ 150
CONTINUE

```
                       !
 ........................................
 :     RANGE(J) = HI2 - SML2            :
 :......................................:
                       !
   @  2001             !
 ........................................
-:                CONTINUE              :
 :......................................:
                       !
                       !---C FIND POPULATION XBAR          !
                       !
 ........................................
 :              SUM = NGON              :
 :         XBAR = STOT/SUM              :
 :......................................:
                       !
                       !---C DETERMINE THE SAMPLE STANDARD !
                       !     DEVIATION                     !
                       !
 ........................................
 : STDEV =(((SUM*SQRTOT)-(STOT**2))/(SUM*(
 : SUM-1.)))**0.5                       :
 :......................................:
                       !
           .......................
           :       RETURN        :
           :.....................:
```

```
SUBROUTINE ANALVR(N,NG)

---C THIS SUBROUTINE ANALYZES THE
   CTEST RESULT DATA FOR EQUALITY OF
   CMEANS
   C SO THAT A DETERMINATION
   CCONCERNING CONTINUED TESTING
   CFREQUENCY CAN
   C BE MADE. IT IS A GENERAL
   CANALYSIS OF VARIANCE THAT CAN BE
   CUSED FOR
   C OTHER APPLICATIONS, IF DESIRED.

COMMON/UINPUT/LR,LW,FMT(19),TITLE(19),
PNIM(19),FMT2(19)
COMMON/STAT1/SQRTOT,STOT,VRAV,INC1
COMMON/STAT2/Y(30),MSER(403),SSDEV,CCMP(
95,5),WOLF(11,400)
COMMON/VALUE1/LABEL(11),DIV1,SP1(8)
DIMENSION TRT(10),BLK(400),TRM(10),SSPOS(
10),DIFSQR(10),TSDEV(10)

---C SQRTOT = SUM OF ALL VALUES
   CSQUARED
   C STOT = SUM OF ALL VALUES
   C TRT(I) = TOTAL OF VALUES FOR
   CEACH TEST POSITION (TREATMENT)
   C TRM(I) = MEAN VALUE FOR EACH
   CPOSITION (TREATMENT)
   C BLK(I) = TOTAL OF VALUES FOR
   CEACH PIECE (BLOCK)
   C SSPOS(I)=SUM OF SQUARED
   CDIFFERENCES
   C TSDEV(I) =TREATMENT SAMPLE
   CSTANDARD DEVIATION
   C SUMDEV = SUM OF ALL TSDEV'S
   C DIFSQR(I) = SQUARED DIFFERENCE
   CBETWEEN TEST VALUE AND MEAN OF
   CPOSITION

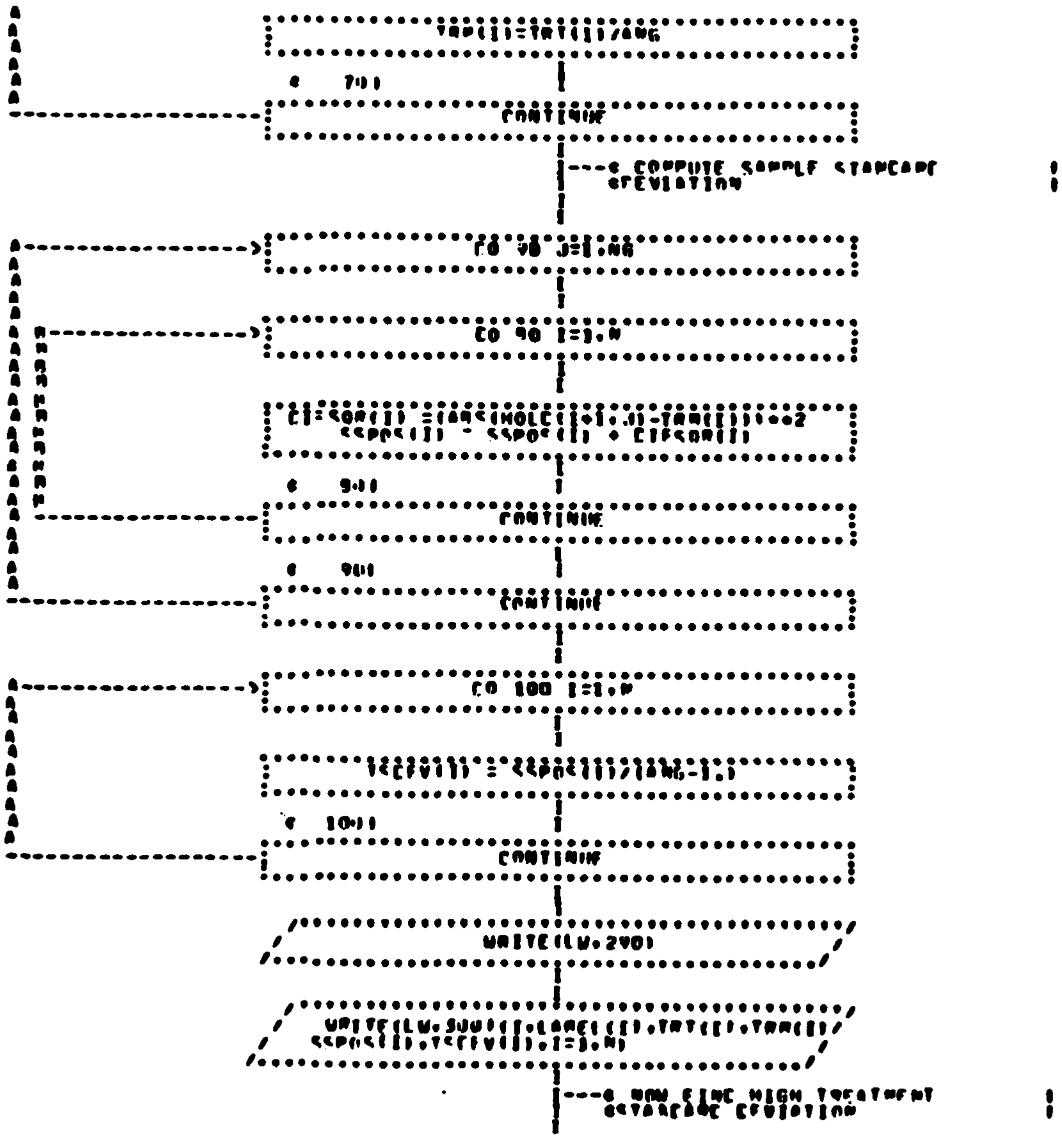
---C INITIALIZATION

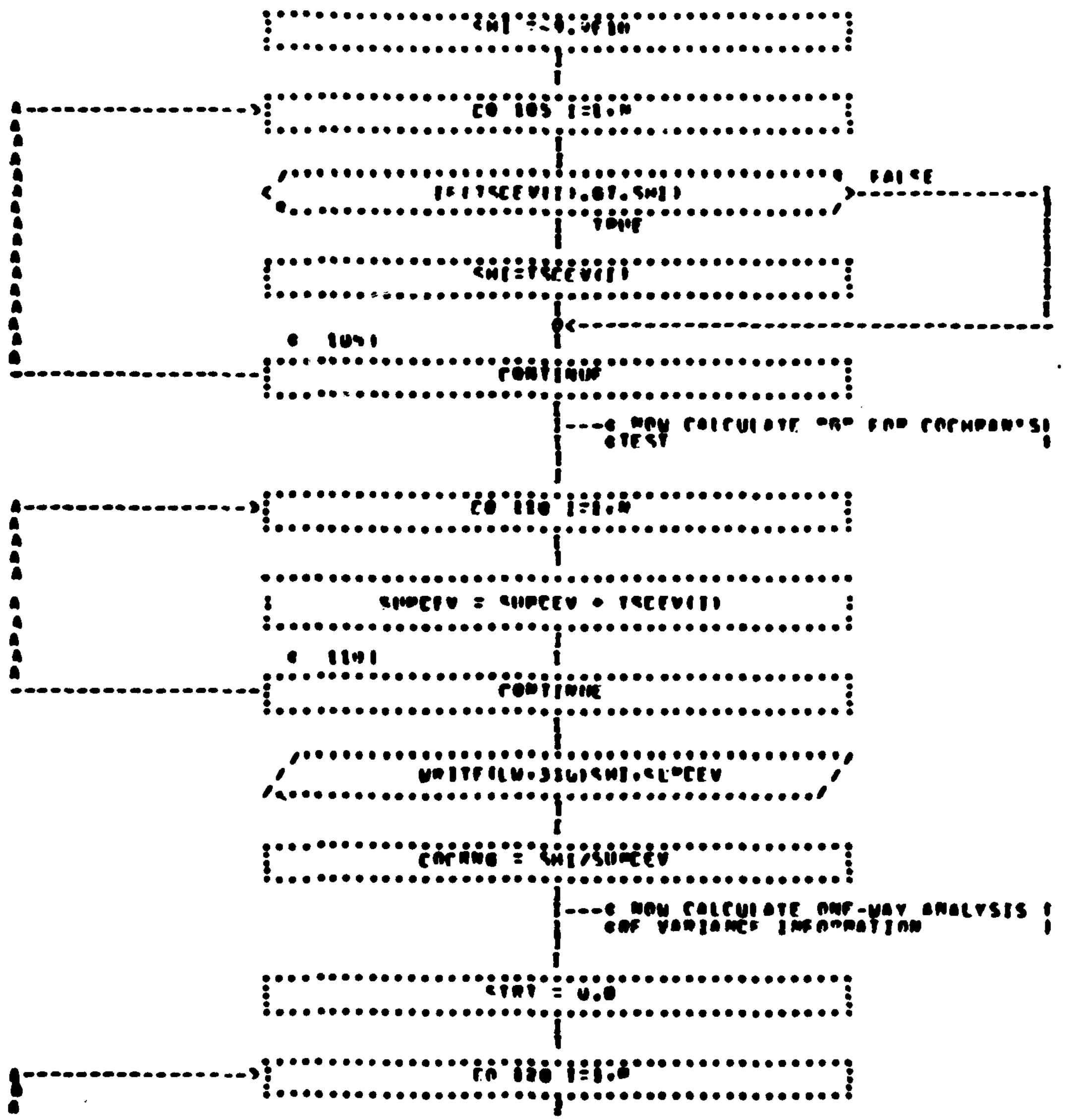
DO 20 I=1,N

TRT(I) = 0.0
TSDEV(I) = 0.0
SSPOS(I) = 0.0

C    201
```

CONTINUE
DO 30 J=1,NG
ALK(J) = 0.0
C 301
CONTINUE
ANA = NG
AN = N
SUMCEV = 0.0
C BEGIN CALCULATION
TOTN = ANA*AN
CON = (STOT**2)/TOTN
SST = SQRTOT - CON
DO 60 J=1,NA
DO 50 I=1,N
ALK(J) = ALK(J) + MOLE(I+1,J)
TRT(I) = TRT(I) + MOLE(I+1,J)
C 501
CONTINUE
C 601
CONTINUE
C COMPUTE TREATMENT MEANS
DO 70 I=1,N


TAP(I)=TAT(I)/ANG
C 701
CONTINUE
C COMPUTE SAMPLE STANDARD DEVIATION
DO 90 J=1,NG
DO 90 I=1,N
DIFSQR(I) =(ABS(HOLD(J+1,I)-TAM(I)))**2
SSPOS(I) = SSPOS(I) + DIFSQR(I)
C 901
CONTINUE
C 901
CONTINUE
DO 100 I=1,N
TSDEV(I) = SSPOS(I)/(ANG-1.)
C 1001
CONTINUE
WRITE(LW,290)
WRITE(LW,SUU)(I,LABEL(I),TAT(I),TAM(I),
SSPOS(I),TSDEV(I),I=1,N)
C NOW FIND HIGH TREATMENT
STANDARD DEVIATION


SHI = -0.9E10
DO 105 I=1,N
IF(TSCEV(I).GT.SHI)
FALSE
TRUE
SHI=TSCEV(I)
105
CONTINUE
C NOW CALCULATE "R" FOR COCHRAN'S TEST
DO 110 I=1,N
SUMCEV = SUMCEV + TSCEV(I)
110
CONTINUE
WRITE(LW,316)SHI,SUMCEV
COCHNG = SHI/SUMCEV
C NOW CALCULATE ONE-WAY ANALYSIS OF VARIANCE INFORMATION
STAT = 0.0
DO 120 I=1,N

```
STRT = STRT + (TRT(I)**2)

C 120
CONTINUE

SSTRT = (STRT/ANB) - CON
SSE = SST - SSTRT
CFTRT = AN-1.
CFTOT = AN*ANB-1.
CFBLK = ANB-1.
CFERR = AN * CFBLK
AMSTRT = SSTRT/CFTRT
AMSE = SSE/CFERR
F = AMSTRT/AMSE

---C NOW CALCULATE TWO-WAY ANALYSIS
   OF VARIANCE RESULTS

SBLK = 0.0

DO 130 J=1,NB

SBLK =SBLK + (BLK(J)**2)

C 130
CONTINUE

SSBLK = (SBLK/AN)-CON
SSE2 = SST - (SSTRT+SSBLK)
CFE2 = CFTRT*CFBLK
AMSBLK = SSBLK/CFBLK
AMSE2 = SSE2/CFE2
F2TRT = AMSTRT/AMSE2
F2BLK = AMSBLK/AMSE2

---C NOW PRINT OUT RESULTS

WRITE(LW,200)

WRITE(LW,210)
```

```
WRITE(LW,220)CFTRT,SSTRT,AMSTRT,F

WRITE(LW,240)CFERR,SSE,AMSE

WRITE(LW,250)CFTOT,SST

WRITE(LW,260)CRCRNG,N,NG

WRITE(LW,270)

WRITE(LW,290)

WRITE(LW,230)

WRITE(LW,220)CFTRT,SSTRT,AMSTRT,F2TRT

WRITE(LW,230)CFBLK,SSBLK,AMSBLK,F2BLK

WRITE(LW,240)CFE2,SSE2,AMSE2

WRITE(LW,250)CFTOT,SST

RETURN

---C FORMATS FOR PRINTOUT

---C 200 FORMAT(1H0,13X,'ONE-WAY
   ANALYSIS OF VARIANCE RESULTS'//
```

```
&TREATMENT MEANS EQUAL'/10X,'
&ALTERNATE HYPOTH. = 1) 2)
&TREATMENT MEANS NOT EQUAL')
C 210 FORMAT(1H0,19X,'DEGREES',7X
&'SUM',10X,'MEAN'/6X,'SOURCE',10X
&'OF',  11X,'OF',9X,'SQUARE',9X,'
&F'/20X,'FREEDOM',5X,'SQUARES')
C 220 FORMAT(1H0,'SAMPLE POSITION'
&,5X,F4.0,5X,F11.3,3X,F10.3,3X,F7
&3)
C 230 FORMAT(1H0,'CAST./FORG. NO.
&,5X,F4.0,5X,F11.3,3X,F10.3,3X,F7
&3)
C 240 FORMAT(1H0,'ERROR',15X,F4.0
&5X,F11.3,3X,F10.3)
C 250 FORMAT(1H0,'TOTAL',15X,F4.0
&5X,F11.3,////)
C 260 FORMAT(1H0,'COCHRAN'S
&EQUALITY OF VARIANCES STATISTIC
&G" =',F7.4 1,3X,'K = ',I2,3X,'F =
&',I3)
C 270 FORMAT(1H0,'NULL HYPOTH. =
&ALL TREATMENT VARIANCES ARE
&EQUAL '/1X, 1'ALT. HYPOTH. = ALL
&TREAT. VARIANCES ARE NOT EQUAL'/
&/)
C 280 FORMAT(1H0,13X,'TWO-WAY
&ANALYSIS OF VARIANCE RESULTS'//,
&10X,'NULL HYPOTHESIS = 1) ALL
&TREATMENT MEANS ARE EQUAL'/29X,'
&2) ALL BLOCK MEANS ARE EQUAL'/
&10X,'ALTERNATE HYPOTH. = 1) ALL
&TREAT. MEANS ARE NOT EQUAL'/30X
&'2) ALL BLOCK MEANS ARE NOT
&EQUAL')
C 290 FORMAT(1H1,'TREATMENT',6X,'
&TOTAL',9X,'MEAN',6X,'SUM SQR
&DIFF',3X,' 1STANDARD DEV'/)
C 300 FORMAT(1H ,I3,1X,'(',A4,')'
&4X,F10.2,3X,F10.2,4X,F10.2,5X,
&F10.2)
C 310 FORMAT(1H0,'HIGH STD.DEV. =
&',F10.2,3X,'TOTAL ALL TREAT. STD
& DEVS 1. = ',F10.2//)
```

END

```
SUBROUTINE VALPLT(NI1,SPL1,NG)

C THIS SUBROUTINE IS DESIGNED TO
CPLOT TEST RESULTS FROM MULTIPLE
C POSITIONS ON EACH CASTING OR
CFORGING. IF THIS SITUATION
CEXISTS.
C THE LABEL PUT ON EACH PLOTTER
CPOINT CORRESPONDS TO THE
CPOSITION
C WITHIN THE FORGING/CASTING FROM
CWHICH THE TEST SAMPLE WAS TAKEN.

COMMON/INPUT/LR,LW,FMT1(30),TITLE(19),
PNUM(14),FMT2(19)
COMMON/PLOT3/UCL,RCL,RBAR,UCLL,RCLL,IPIN,
COMMON/STAT2/V(10),NSER(903),SSDEV,COMPI
COMMON/VALUE3/LABEL(31),CIV1,SP1(9)
DIMENSION NOM(11),NAME(19),LINE(101)
DATA NAME/' ','-','+','*','0','3','8','9'
MOD(K)=K-(K/10)*10

IF(NG.GT.15)   FALSE
TRUE
WRITE(LW,105)

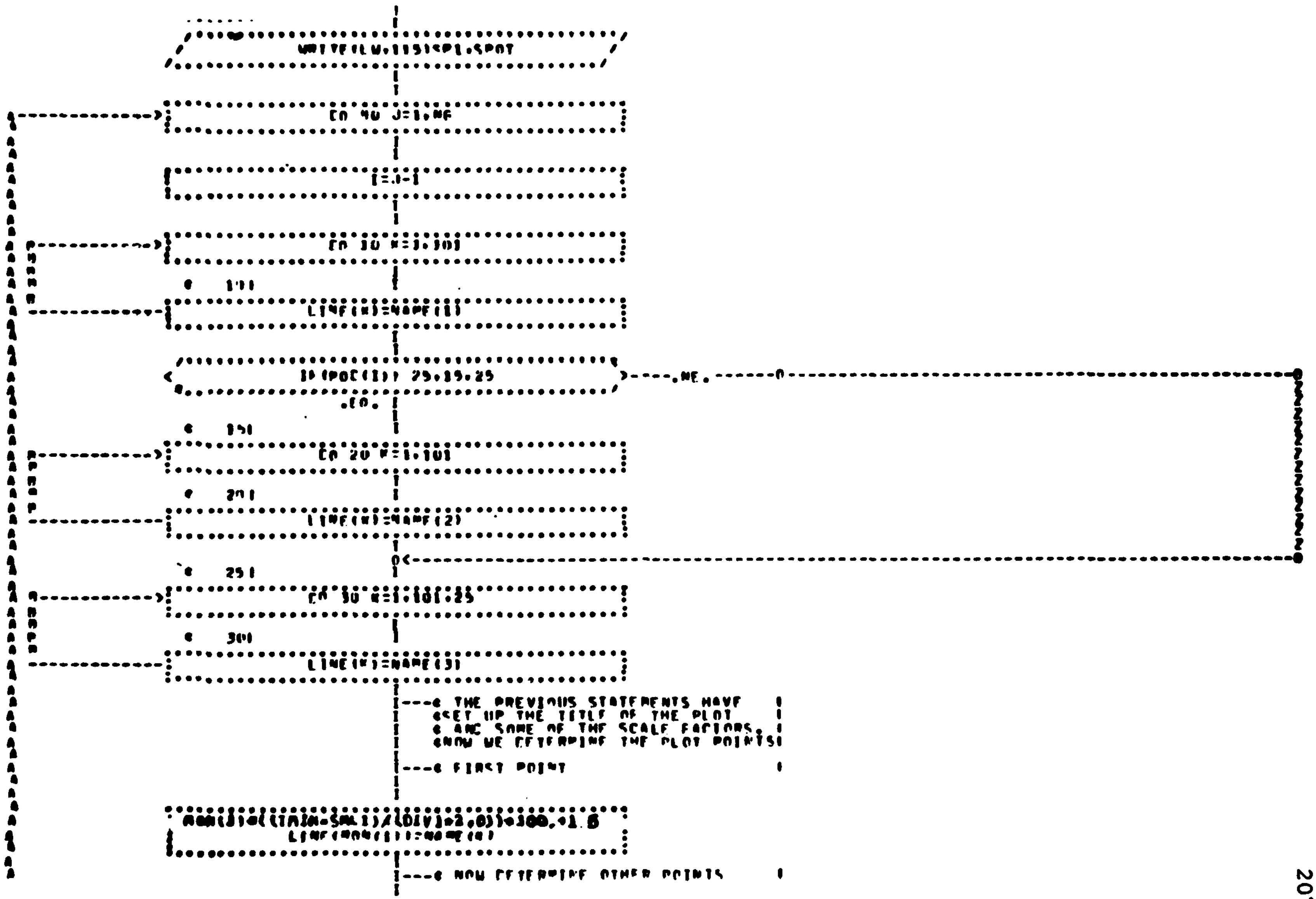
WRITE(LW,100)TITLE

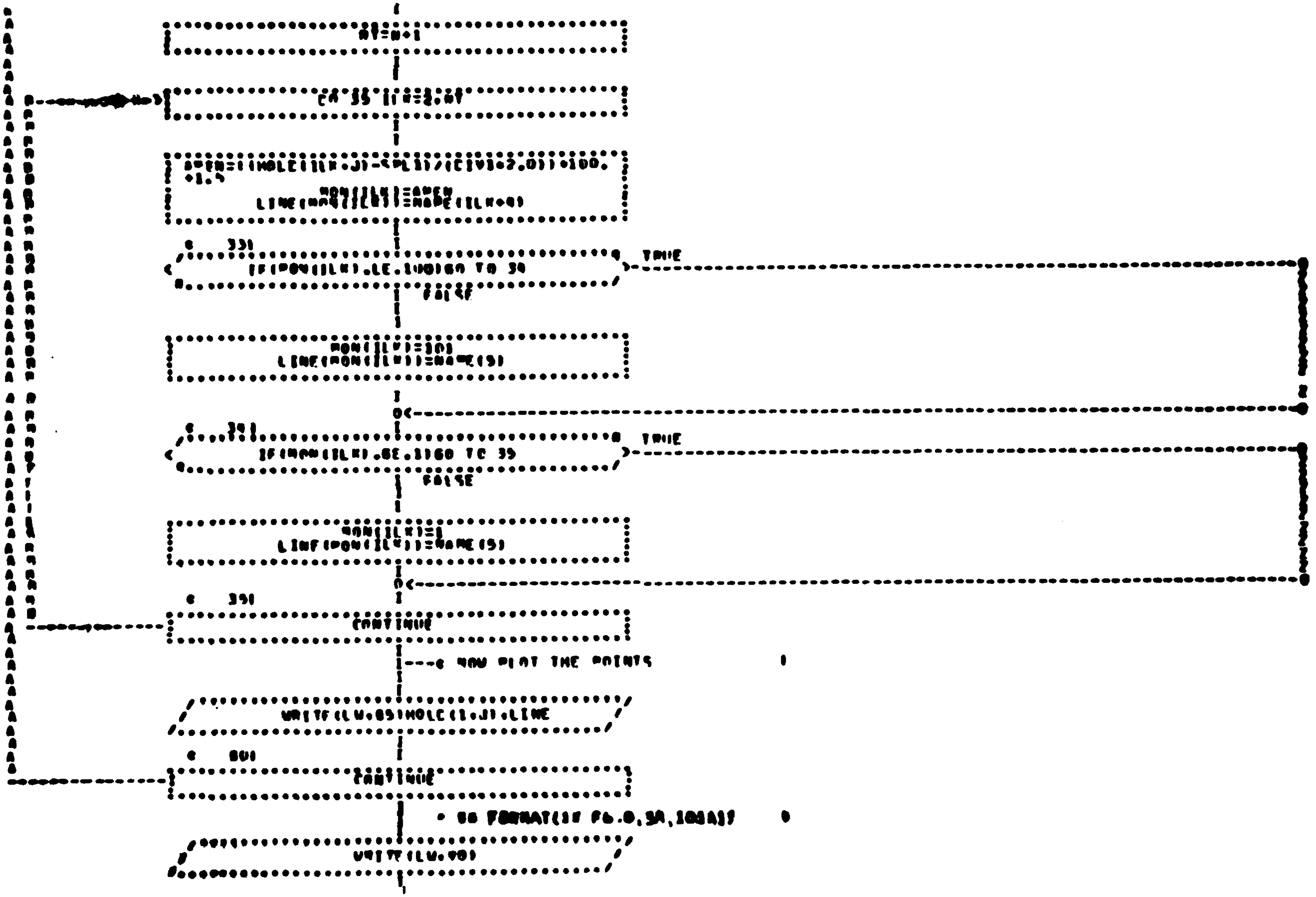
WRITE(LW,110)PNUM

WRITE(LW,112)

WRITE(LW,113)

SML1=SML1-5
   ----SP1 = SML1
SP(2)=SML1+(CIV1*2.0)
SP1(2)=SML1+(CIV1*0.5)
SP1(3)=SML1+(CIV1)
SP1(4)=SML1+(CIV1*1.5)
```


WRITE(LW,115)SPL,SPOT
DO 40 J=1,NE
I=J-1
DO 10 K=1,101
LINE(K)=NAME(1)
IF(POC(I)) 25,15,25
.NE.
.EQ.
DO 20 K=1,101
LINE(K)=NAME(2)
DO 30 K=1,101,25
LINE(K)=NAME(3)
C THE PREVIOUS STATEMENTS HAVE
C SET UP THE TITLE OF THE PLOT
C AND SOME OF THE SCALE FACTORS.
C NOW WE DETERMINE THE PLOT POINTS
C FIRST POINT
C NOW DETERMINE OTHER POINTS


TRUE
FALSE
TRUE
FALSE
CONTINUE
C NOW PLOT THE POINTS
CONTINUE

```
|---& 99 FORMAT(1H0,//,9X,'NOTE: 1)          |
|   &MISSING NUMBERS INDICATE                |
|   &DUPLICATION.' /,10X,'CHECK DATA         |
|   &ACCORDING TO SERIAL NUMBER FOR          |
|   &DUPLICATES.' //,10X,'2) AN              |
|   &ASTERISK (*) INDICATES A VALUE          |
|   &OUT OF LIMITS.')                        |
|
.....................
:      RETURN       :
.....................

|---& 100 FORMAT(1H0,19A4)                   |
|   & 105 FORMAT(1H1)                        |
|   & 110 FORMAT(1H0,'VALUE PLOT:'/          |
|   &15X,'(SERIAL NUMBER VS.                 |
|   &INDIVIDUAL TEST MEASUREMENTS)'          |
|   &/30X,'PART NUMBER: ',19A4)              |
|   & 112 FORMAT(1H0,45X,'NUMBER ON          |
|   &PLOT CORRESPONDS TO POSITION            |
|   &NUMBER'/60X 1.'(I.E., 3 = TEST          |
|   &SAMPLE FROM POSITION 3 OF               |
|   &CASTING/FORGING')                       |
|   & 113 FORMAT(1H0,'SERIAL',36X,'          |
|   &INDIVIDUAL TEST MEASUREMENTS'/1X        |
|   &'NUMBER' ))                             |
|   & 115 FORMAT(1H0,1X,4(F12.3,13X),        |
|   &F12.3)                                  |
|
.....................
:        END        :
.....................
```

```
BEGIN

--- MAIN PROGRAM

--- THIS PROGRAM WILL CALCULATE THE
    T- STATISTIC FOR PAIREC
    OBSERVATIONS
    THAT ARE NORMALLY CISTRIBUTEC
    ANC WILL ALSO YIELC THE
    CIFFERENCES FOR
    EACH PAIR FOR THE NON-PARAMETRI
    WILCOXON PAIREC T-TEST.

CIMENSION CIFF(400),CIF2(400),CATE(7),
PNUM(24)

--- REAC IN CESCRIPTIVE VALUES
    CONCERNING CATA

101
REAC(5,20)NG,CMU

--- 20 FORMAT(I4,F10.2)

IF(NG.EQ.0)GO TO 300          TRUE
FALSE

--- ANG=NG= THE NUMBER OF CATA
    PAIRS
    CMU = THE VALUE TO BE INVESTIGA
    EC BY THE HYPOTHESIS:HO: U1-U2 =
    CMU
    VALCRT = THE VALUE (AVERAGE)
    CETERMINEC FROM MANUFACTURER'S
    TESTS.
    VALCMR = THE VALUE (AVERAGE)
    CETERMINEC FROM ARC CO. TESTING
    CIFF(I) = THE CIFFERENCE
    BETWEEN VALCRT ANC VALCMR
    CIF2(I) = THE CIFFERENCE (CIFF(
    I)) SQUAREC
    SUMCIF = THE SUM OF THE
    CIFFERENCES
    SQRCIF = SUM OF THE CIFFRENCES
    SQUAREC
    SCC = STANCARC CEVIATION OF THE
    CIFFERENCES
    CAVG = THE AVERAGE CIFFERENCE
    SCSQR = THE SAMPLE VARIANCE OF
    THE CIFFERENCES
    TSCAR = THE -T- STATISTIC FOR
    INVESTIGATING HO: THE NULL
    HYPOTH.
    NCOF = THE NUMBER OF CEGREES OF
    FREECOM.
```

```
CO 30 I=1,NG                         ---$ INITIALIZATION

CIFF(I)=0.0
CIF2(I)=0.0

$   30I
CONTINUE

ANG = NG
NCOF = NG - 1
SUMCIF = 0.0
SORCIF = 0.0

I---$ BEGIN CALCULATION ANC PRINT-OUT
     $CATA ANC RESULTS

REAC(5,175)CATE

REAC(5,190)PNUM

WRITE(6,205)PNUM,CATE

WRITE(6,206)

CO 80 I=1,NG

REAC(5,200)SNMBR,VALCRT,VALCMR

CIFF(I) = VALCRT-VALCMR
SUMCIF = SUMCIF+CIFF(I)
CIF2(I) = ABS(CIFF(I))**2
SORCIF = SORCIF+CIF2(I)

WRITE(6,203)SNMBR,VALCRT,VALCMR,CIFF(I)
,CIF2(I)
```

```
C   801
        CONTINUE

        WRITE(6,202)SUMCIF,SQRCIF

SCSQR = ((ANG*SQRCIF)-(SUMCIF**2))/(ANG*(
ANG-1.))
        SCC = SQRT(ABS(SCSQR))
         CAVG = SUMCIF/ANG
TSTAR = (CAVG-CMU)/(SCC/(SQRT(ANG)))

        WRITE(6,203)SCSQR,SCC,CAVG,NCOF

        WRITE(6,204)TSTAR

        GO TO 10

C FORMAT STATEMENTS FOLLOW

C 175 FORMAT(7A4)
C 180 FORMAT(24A1)
C 200 FORMAT(I5,2F10.3)
C 201 FORMAT(1H0,I5,5X,F10.3,5X,
CF10.3,3X,F9.4,3X,F9.4)
C 202 FORMAT(1H0,'TOTAL',33X,F9.4
C2X,F10.4//)
C 203 FORMAT(1H0,'SAMPLE VARIANCE
C= ',F10.3,3X,'SAMPLE STANCARC
CCEV. = ' ),F10.2,3X,'AVERAGE
CCIFFERENCE = ',F7.4,3X,'CEG. OF
CFREECOM = ',I3/ 2)
C 204 FORMAT(1H0,'THE "T"
CSTATISTIC FOR TESTING THE
CCIFFERENCE IN THE T TWO TESTING
CMEANS = ',F7.4/10X,'NULL HYPOTH.
C U1-U2 = CMU'/10X,'AL 2T. HYPOTH
C: U1-U2.NE.CMU'//10X,'ASSUMPTION
C THE CISTRIBUTION UNC ERLYING
CTHE CIFFERENCES IS NORMAL.')
C 205 FORMAT(1H1,'CETERMINATION
COF A CIFFERENCE IN TESTING FOR'/
C20X,'PAR IT NUMBER: ',24A1,'
CTESTING VS. ARC CO. TESTING'/40X
C'CATA FROM ',7 2A4//)
C 206 FORMAT(1H0,'SER.NO.',4X,'
CCERT CATA',6X,'CMR CATA'5X,'
CCIFFERENCE',2 1X,'CIFF. SQRC'/)

C   300
        STOP
```

APPENDIX D

APPENDIX D

```
C   MAIN PROGRAM
C   THIS IS THE MAIN PROGRAM FOR DETERMINING QUALITY CHARTS FOR ARC CO.
C   CASTINGS AND FORGINGS.  IT IS TO BE USED IN CONJUNCTION
C   WITH THE SUBROUTINES SPECIFIED IN THE APPROPRIATE MANUAL.
C
      COMMON/UINPUT/LR,LW,FMT(19),TITLE(19),PNUM(19),FMT2(19)
      COMMON/STAT1/SORTOT,STOT,XBAR,INCI
      COMMON/STAT2/X(10),NSER(403),SSDEV,COMP(55,5),HOLE(11,403)
      COMMON/PLOT1/UCL,RCL,RBAR,UCLL,RCLL,TMIN,N
      COMMON/VALUE1/LABEL(11),DIV1,SP1(4)
      DIMENSION D3(10),D4(10),A2(10),RANGE(403),SUBAR(403),DD2(10),DD3(
     110)
C   THE FOLLOWING DATA STATEMENTS CONTAIN VALUES FOR D3, D4, AND A2 FOR
C   FINDING THE APPROPRIATE CONTROL LIMITS USING STANDARD TERMINOLOGY.
C   IF ANOTHER METHOD OF DETERMINING THESE LIMITS (OTHER THAN 3 SIGMA)
C   THE DATA MAY BE CHANGED, VALUES FOR THE LIMITS MAY BE INPUTTED, OR
C   A DIFFERENT CALCULATION METHOD MAY BE INCLUDED IN THE PROGRAM!!!!
C
      DATA D3/0.0,0.0,0.0,0.0,0.0,0.0,.08,.14,.18,.22/,
     1D4/0.0,3.27,2.57,2.28,2.11,2.00,1.92,1.86,1.82,1.78/,
     2A2/0.0,1.88,1.02,.73,.58,.48,.42,.37,.34,.31/,
     3DD2/1.0,1.13,1.69,2.06,2.33,2.53,2.70,2.85,2.97,3.08/,
     4DD3/.94,.95,.99,.99,.96,.95,.93,.92,.91,.90/
C
C   NG = NUMBER OF SUBGROUPS
C   N  = NUMBER OF ELEMENTS IN THE SUBGROUP
C   ISKIP = MEANS OF SUPPRESSING PRINTING OF MEANS AND RANGES (01)
C   INLIM = 01, IF USER WISHES TO SPECIFY THE MEANS AND CONTROL LIMITS.
C
      LR=5
      LW=6
   10 READ(LR,15)TITLE
        READ(LR,15)PNUM
      WRITE(LW,16)TITLE
      WRITE(LW,35)PNUM
   15 FORMAT(19A4)
   16 FORMAT(1H1,19A4)
      READ(LR,20)NG,N,ISKIP,INLIM,IPLOT
   20 FORMAT(I3,4I2)
      WRITE(LW,25)NG,N,ISKIP,INLIM,IPLOT
   25 FORMAT(1H0,I3,5X,I2,5X,I2,5X,I2,5X,I2)
      IF(N.EQ.0) GO TO 100
C
C   FMT=FORMAT SPECIFICATION AS INPUT BY THE USER
C
      READ(LR,30)FMT
   30 FORMAT(19A4)
      WRITE(LW,35)FMT
   35 FORMAT(1H0,19A4)
C
C    THE FOLLOWING FOUR STATEMENTS DETERMINE VALUES FOR THE VALUE
C     PLOT IN THE EVENT THERE ARE MEASUREMENTS FROM MULTIPLE
C    LOCATIONS ON THE CASTING OR FORGING..
C
      IF(N.EQ.1)GO TO 36
      READ(LR,15)FMT2
      WRITE(LW,35)FMT2
      READ(LR,FMT2)(LABEL(I),I=1,N)
      WRITE(LW,39)(LABEL(I),I=1,N)
   36 READ(LR,37)TMIN
   37 FORMAT(F10.3)
      WRITE(LW,40)
   39 FORMAT(1H0,8A8)
   40 FORMAT('0','SERIAL #',20X,'INPUT DATA BY POSITION')
      SORTOT = 0.0
      STOT = 0.0
      INCI = 0
C    THE FOLLOWING STATEMENTS INITIALIZE THE HOLE ARRAY
      DO 42 J=1,400
      DO 41 I=1,11
   41 HOLE(I,J) = 0.0
   42 CONTINUE
C
C   SUBROUTINE ASTATS IS NOW CALLED TO DETERMINE SUBGROUP AVERAGES AND
C   MEANS, THE POPULATION MEAN , AND THE POPULATION STANDARD DEVIATION.
C
   43 CALL ASTATS (RANGE,SUBAR,NG,N)
      WRITE(LW,44)XBAR,SSDEV,STOT,SORTOT
   44 FORMAT(1H0,'THE MEAN =',F10.2,5X,'STAND DEV =',F10.2,5X,'SUM =',F1
     10.2,5X,'SUM OF SQUARES =',F10.2)
      IF(N.EQ.1)GO TO 46
      IF(INCI.EQ.2)GO TO 49
      CALL ANALVR(N,NG)
C   NOW A SORT IS PERFORMED TO DETERMINE THE LARGEST RANGE AND SUBGROUP
C   MEAN FOR SCALING USE.
C
      SML = 9.9E10
      HI  =-9.9E10
      SML1=SML
      HI1 =HI
      CALL SORTS(SML,HI,RANGE,NG)
      CALL SORTS(SML1,HI1,SUBAR,NG)
```

```
C
C     NOW CALCULATE RBAR
C
      SUMR = 0.0
      DO 50 I=1,NG
   50 SUMR = SUMR + RANGE(I)
      R = NG
      RBAR = SUMR/R
C
C     NOW CALCULATE LIMITS FOR RCHARTS
C
      UCL = D4(N)*RBAR
      BCL = D3(N)*RBAR
C
C     NOW CALCULATE LIMITS FOR XBAR CHARTS
C
      SIG3 = A2(N)*RBAR
      UCLL= XBAR + SIG3
      BCLL= XBAR - SIG3
C
C     REPLACE CONTROL LIMIT VALUES IF USER DESIRES TO INPUT THEM.
C
      IF(INLIM.EQ.1)READ(LR,60)BCL,RBAR,UCL,BCLL,XBAR,UCLL
   60 FORMAT(6F10.0)
C
C     THE FOLLOWING STATEMENTS CALL SUBROUTINE CHARTS FOR PRODUCTION OF
C     THE DESIRED CONTROL CHARTS.
C
      WRITE(LW,61)
   61 FORMAT('1')
      NNCEV = 3
      CALL CHARTS (HI,HI1,SML,SML1,NG,RANGE,SUBAR,NNCEV)
      IF(NG.GT.15)WRITE(LW,62)
   62 FORMAT(1H1)
      NNCEV = NNCEV-1
      REC = 2./3.
      RAN = RBAR*DD3(N)/DD2(N)
      UCL = UCL - RAN
      BCL = RBAR - 2. * RAN
      IF(BCL.LT.0.0) BCL = 0.0
      UCLL = XBAR + (SIG3*REC)
      BCLL = XBAR - (SIG3*REC)
      CALL CHARTS(HI,HI1,SML,SML1,NG,RANGE,SUBAR,NNCEV)
      IF(INCI.EQ.2) GO TO 95
      IF(NG.GT.15)WRITE(LW,63)
   63 FORMAT(1H1)
      NNCEV = NNCEV-1
      UCL = UCL - RAN
      BCL = RBAR - RAN
      IF(BCL.LT.0.0) BCL = 0.0
      UCLL = XBAR + (SIG3/3.)
      BCLL = XBAR - (SIG3/3.)
      CALL CHARTS(HI,HI1,SML,SML1,NG,RANGE,SUBAR,NNCEV)
C
      IF(IPLOT.NE.0) GO TO 10
      WRITE(LW,62)
      CALL VALPLT(HI1,SML1,NG)
C
      GO TO 10
   66 STOT = 0.0
      SQRTOT = 0.0
      INCI = 2
      N = 3
      NG = NG/N
      DO 75 I=1,NG
      DO 70 J=1,N
      M=I*N - (N - J)
      COMP(I,J) = SUBAR (M)
   70 CONTINUE
   75 CONTINUE
      WRITE(LW,90)
   90 FORMAT('1')
      GO TO 43
   95 NG = (NG*3)+2
      DO 90 J=1,NG
      NSER(J)=HOLD(1,J)
      SUBAR(J)=HOLD(2,J)
   90 CONTINUE
      INCI = 3
      BLIM = 3. * RBAR/DD2(N)
      UCLL = XBAR + BLIM
      BCLL = XBAR - BLIM
      CALL CHARTS(HI,HI1,SML,SML1,NG,RANGE,SUBAR,NNCEV)
      GO TO 10
  100 STOP
      END
```

```
      SUBROUTINE CHARTS (HI,HI1,SML,SML1,NG,RANGE,SUBAR,NNCEV)
C
C  THIS SUBROUTINE WILL PRODUCE X-BAR AND RANGE CHARTS FOR THE
C  INPUT DATA.  USE CAUTION WHEN MODIFYING!!!!!
C
      COMMON/UINPUT/LR,LW,FMT(19),TITLE(19),PNUM(19),FMT2(19)
      COMMON/STAT1/SORTOT,STOT,XBAR,INCI
      COMMON/STAT2/ X(10),NSER(403),SSCEV,CORP(95,5),HOLC(11,400)
      COMMON/PLOT1/UCL,RCL,RBAR,UCLL,RCLL,TMIN,N
      COMMON/VALUE1/LABEL(11),CIV1,SP1(4)
      DIMENSION KALER(403),IVECTR(37),IVECTX(37),KALEX(403)
     1,RANGE(403),SUBAR(403),SP2(4),M(403)
      DATA IBLANK/' '/,IPOINT/'.'/,IONE/'1'/,IDASH/'-'/,
     1BLANK/' '/,IAST/'*'/,IM/'M'/
      WRITE(LW,90)TITLE
      WRITE(LW,91)PNUM
   91 FORMAT('0','PART NUMBER:   ',19A4)
      IF(INCI.EQ.3)GO TO 299
   90 FORMAT(1H0,//,19A4)
      IF(INCI.EQ.2) WRITE(LW,93)N
   93 FORMAT('0','CHARTS FOR GROUPS OF ',I2,' CASTINGS/FORGINGS')
      IF(NNCEV-2)  98,99,94
   94 IF(NNCEV.EQ.3)WRITE(LW,95)
   95 FORMAT('0',30X,'3 SIGMA-',65X,'3 SIGMA-')
      GO TO 100
   99 IF(NNCEV.EQ.2)WRITE(LW,90)
   90 FORMAT('0',30X,'2 SIGMA-',65X,'2 SIGMA-')
      GO TO 100
   98 IF(NNCEV.EQ.1)WRITE(LW,75)
   75 FORMAT('0',30X,'1 SIGMA-',65X,'1 SIGMA-')
  100 WRITE (LW,105)
  105 FORMAT(1H ,29X,'RANGE CHART',62X,'X-BAR CHART',//)
      WRITE (LW,110) RCL,RCLL,RBAR,XBAR,UCL,UCLL
  110 FORMAT(' ',17X,'LCL=',F10.4,59X,'LCL=',F10.4/
     130X,'CENTER=',F10.4,17X,'SERIAL',33X,'CENTER=',F10.4/39X,'UCL=',
     2F10.4,13X,6HNUMBER,43X,'UCL=',F10.4//)
  115 IF (UCL.GT.HI) HI=UCL
      IF (UCLL.GT.HI1) HI1=UCLL
      IF (RCL.LT.SML)  SML=RCL
      IF (RCLL.LT.SML1)SML1=RCLL
      IF (TMIN.LT.RCLL)SML1=TMIN
C
C  FIND SCALE VALUES FOR XBAR AND RANGE CHARTS
C
      CALL SCALE(HI,SML,SP2,CIV,SB)
      CALL SCALE(HI1,SML1,SP1,CIV1,RA1)
      NT=NG+3
      RANGE(NT-2)=RCL
      RANGE(NT-1)=RBAR
      RANGE(NT)  =UCL
      SUBAR(NT-2)=RCLL
      SUBAR(NT-1)=XBAR
      SUBAR(NT)  =UCLL
      WIDR=CIV/36.
      WIDX=CIV1/36.
      DO 135 I=1,NT
      GPR=SML+WIDR/2.0
      GPX=SML1+WIDX/2.0
      DO 120 J=1,37
      IF(RANGE(I).LE.GPR)GO TO 125
  120 GPR=GPR+WIDR
      J=37
  125 KALER(I)=J
      GPX2 = SML1+WIDX/2.0
      DO 126 J=1,37
      IF(TMIN.LE.GPX2) GO TO 127
  126 GPX2 = GPX2+WIDX
      J=1
  127 M(I) = J
      DO 130 J=1,37
      IF(SUBAR(I).LE.GPX)GO TO 135
  130 GPX=GPX+WIDX
      J=37
  135 KALEX(I)=J
C
C  LOGIC FOR COINCIDING LIMITS
C
      IF(KALER(NT-2).EQ.KALER(NT-1).OR.KALER(NT-1).EQ.
     1KALER(NT))WRITE(LW,140)
  140 FORMAT('0',17X,' - YOUR LIMITS MAY COINCIDE')
      IF(KALEX(NT-2).EQ.KALEX(NT-1).OR.KALEX(NT-1).EQ.
```

```
     1KALEX(NT))WRITE(LW,150)
  150 FORMAT('+',94X,' - YOUR LIMITS MAY COINCIDE')
C
C    PRINT SCALE VALUES FOR XBAR AND R CHARTS
C
      IF(INCI.NE.3)GO TO 155
      WRITE(LW,160)SP1
      GO TO 175
  155 WRITE(LW,160)SP2
  160 FORMAT(' ',9X,4(F12.3))
      WRITE(LW,170)SP1
  170 FORMAT('+',92X,4(F12.3))
C
C    PRINT FOR SCALES
C
  175 DO 190 J=1,37
      IVECTR(J)=IDASH
  190 IVECTX(J)=IDASH
      DO 200 J=1,37,I2
      IVECTX(J)=IPOINT
  200 IVECTR(J)=IPOINT
      IF(INCI.NE.3)GO TO 205
      WRITE(LW,207)IVECTX
  207 FORMAT(' ',17X,37A1)
      GO TO 215
  205 WRITE(LW,210)IVECTR,IVECTX
  210 FORMAT(' ',17X,37A1,36X,37A1)
C
C    GRAPH OF XBAR AND RANGE CHARTS
C
  215 DO 250 I=1,NG
      DO 220 JK=1,37
      IVECTR(JK)=IBLANK
  220 IVECTX(JK)=IBLANK
      IVECTR(KALER(NT))=IONE
      IVECTR(KALER(NT-2))=IONE
      IVECTR(KALER(NT-1))=IONE
      IVECTX(KALEX(NT-2))=IONE
      IVECTX(KALEX(NT-1))=IONE
      IVECTX(KALEX(NT))=IONE
      IVECTX(M(I)) = IM
      IVECTR(KALER(I))=IAST
      IVECTX(KALEX(I))=IAST
C
C     THE GRAPHING OF SUBGROUPS TAKES PLACE NOW!!!!!!
C
      IF(INCI.EQ.3)GO TO 245
      IF(ISKIP.NE.0) GO TO 240
      WRITE(LW,230)RANGE(I),IVECTR,NSER(I),SUBAR(I),IVECTX
  230 FORMAT(' ',F12.3,5X,37A1,10X,I5,5X,F12.3,4X,37A1)
      GO TO 250
  240 WRITE(LW,210)IVECTR,IVECTX
  245 IF(ISKIP.NE.0)GO TO 247
      WRITE(LW,246)SUBAR(I),IVECTX,NSER(I)
  246 FORMAT(' ',F12.3,5X,37A1,10X,I5)
      GO TO 250
  247 WRITE(LW,249)IVECTX,NSER(I)
  249 FORMAT(' ',17X,37A1,10X,I5)
  250 CONTINUE
       RETURN
  299 WRITE(LW,300)
  300 FORMAT('0',30X,'INDIVIDUAL VALUE'/34X,'X CHART')
      WRITE(LW,310)RCLL,XBAR,UCLL
  310 FORMAT(' ',17X,'LCL=',F10.4/30X,'CENTER=',F10.4,17X,
     1'SERIAL '/39X,'UCL=',F10.4,13X,6HNUMBER//)
      GO TO 115
      END
```

```
      SUBROUTINE SORTS (AL,BR,CH,NN)
      DIMENSION CH(403)
      DO 50 I=1,NN
      IF(CH(NN).LT.AL) AL=CH(NN)
      IF(CH(NN).GT.BR) BR=CH(NN)
   50 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SCALE (H,B,SP,RAP,SB)
C
C  THIS SUBROUTINE MUST BE INCLUDED WITH SUBROUTINE CHARTS
C  FOR SUCCESSFUL CHARTING OF DATA!!!!!!!!
C
      DIMENSION CRE(9),SP(4)
      SP(1)=B
      SP(4)=H
      SP(2)=B+(H-B)/3.
      SP(3)=H-(H-B)/3.
      SB=B
      RAP=SP(4)-SP(1)
      RETURN
      END
```

```
      SUBROUTINE ASTATS (RANGE,SUBAR,NG,N)
C
C THIS SUBROUTINE WILL DETERMINE THE SAMPLE AVERAGE,SUBGROUP
C AVERAGES,SUBGROUP RANGES,AND SAMPLE STANDARD DEVIATION
C OF THE INPUT DATA
C
      COMMON/UINPUT/LR,LW,FMT(19),TITLE(19),PNUM(19),FMT2(19)
      COMMON/STAT1/SQRTOT,STOT,XBAR,INCI
      COMMON/STAT2/X(10),NSER(403),SSDEV,COMP(95,5),HOLD(11,400)
      DIMENSION RANGE(403),SUBAR(433)
      DO 200 J=1,NG
C
C  THE FOLLOWING STATEMENT READS IN THE TEST DATA.
C  "NSER" IS THE SERIAL NUMBER OF THE CASTING/FORGING -
C  IF THIS IS NOT TO BE INCLUDED, CHANGE FORMAT STATEMENTS
C  NUMBER 13 AND FMT.
C
      IF(INCI.EQ.2)GO TO 10
      GO TO 14
   10 NSER(J)=J
      DO 12 I=1,N
      X(I) = COMP(J,I)
   12 CONTINUE
      WRITE(LW,13)NSER(J),(X(J7),J7=1,N)
   13 FORMAT('0',I5,5F10.2)
      GO TO 25
   14 READ (LR,FMT)NSER(J),(X(J7),J7=1,N)
      HOLD(1,J)=NSER(J)
       DO 15 I=1,N
        HOLD(I+1,J)=X(I)
   15  CONTINUE
      WRITE(LW,20)
   20 FORMAT(1H0)
      WRITE(LW,FMT)NSER(J),(X(J7),J7=1,N)
C
C  NOW SUM THE X VALUES
C
   25 SUMX = 0.0
      SUMSQ= 0.0
      DO 100 I=1,N
      SUMX  =  SUMX + X(I)
      SUMSQ = SUMSQ + (X(I)**2)
  100 CONTINUE
C
C  FIND THE GRAND SUMS
C
      STOT  =  STOT + SUMX
      SQRTOT=SQRTOT + SUMSQ
C
C  FIND THE SUBGROUP MEAN ** XBAR
      SUBAR(J) = SUMX/N
C
C  SORT TO FIND THE HI AND LO VALUES FOR RANGE
C
      HI2 = -9.9E10
      SML2=  9.9E10
      DO 150 I=1,N
      IF (X(I).LT.SML2) SML2=X(I)
      IF (X(I).GT.HI2) HI2=X(I)
  150 CONTINUE
      RANGE(J) = HI2 - SML2
  200 CONTINUE
C
C  FIND POPULATION XBAR
C
      SUM = NG*N
      XBAR = STOT/SUM
C
C  DETERMINE THE SAMPLE STANDARD DEVIATION
C
      SSDEV =(((SUM*SQRTOT)-(STOT**2))/(SUM*(SUM-1.)))**0.5
      RETURN
      END
```

```
      SUBROUTINE ANALVR(N,NG)
C
C  THIS SUBROUTINE ANALYZES THE TEST RESULT DATA FOR EQUALITY OF MEANS
C  SO THAT A DETERMINATION CONCERNING CONTINUED TESTING FREQUENCY CAN
C  BE MADE.  IT IS A GENERAL ANALYSIS OF VARIANCE THAT CAN BE USED FOR
C  OTHER APPLICATIONS, IF DESIRED.
C
      COMMON/UINPUT/LR,LW,FMT(19),TITLE(19),PNUM(19),FMT2(19)
      COMMON/STAT1/SQRTOT,STOT,XBAR,INCI
      COMMON/STAT2/Y(10),NSER(403),SSDEV,COMP(95,5),HOLD(11,400)
      COMMON/VALUE1/LABEL(11),DIV1,S21(4)
      DIMENSION TRT(10),BLK(400),TRM(10),SSPOS(10),DIFSQR(10),TSDEV(10)
C
C SQRTOT = SUM OF ALL VALUES SQUARED
C STOT   = SUM OF ALL VALUES
C TRT(I) = TOTAL OF VALUES FOR EACH TEST POSITION (TREATMENT)
C TRM(I) = MEAN VALUE FOR EACH POSITION (TREATMENT)
C BLK(J) = TOTAL OF VALUES FOR EACH PIECE (BLOCK)
C SSPOS(I)=SUM OF SQUARED DIFFERENCES
C TSDEV(I) =TREATMENT SAMPLE STANDARD DEVIATION
C SUMDEV = SUM OF ALL TSDEV'S
C DIFSQR(I) = SQUARED DIFFERENCE BETWEEN TEST VALUE AND MEAN OF POSITION
C
C INITIALIZATION
C
      DO 20 I=1,N
      TRT(I) = 0.0
      TSDEV(I) = 0.0
      SSPOS(I) = 0.0
   20 CONTINUE
      DO 30 J=1,NG
      BLK(J) = 0.0
   30 CONTINUE
      ANG = NG
      AN  = N
      SUMDEV = 0.0
C
C  BEGIN CALCULATION
C
      TOTN = ANG*AN
      CON = (STOT**2)/TOTN
      SST = SQRTOT - CON
      DO 60 J=1,NG
      DO 50 I=1,N
      BLK(J) = BLK(J) + HOLD(I+1,J)
      TRT(I) = TRT(I) + HOLD(I+1,J)
   50 CONTINUE
   60 CONTINUE
C
C  COMPUTE TREATMENT MEANS
C
      DO 70 I=1,N
      TRM(I)=TRT(I)/ANG
   70 CONTINUE
C
C  COMPUTE SAMPLE STANDARD DEVIATION
C
      DO 90 J=1,NG
      DO 80 I=1,N
      DIFSQR(I) =(ABS(HOLD(I+1,J)-TRM(I)))**2
      SSPOS(I) = SSPOS(I) + DIFSQR(I)
   80 CONTINUE
   90 CONTINUE
      DO 100 I=1,N
      TSDEV(I) = SSPOS(I)/(ANG-1.)
  100 CONTINUE
      WRITE(LW,290)
      WRITE(LW,300)(I,LABEL(I),TRT(I),TRM(I),SSPOS(I),TSDEV(I),I=1,N)
C
C NOW FIND HIGH TREATMENT STANDARD DEVIATION
C
```

```
      SHI =-9.9E10
      DO 105 I=1,N
      IF(TSDEV(I).GT.SHI)SHI=TSDEV(I)
  105 CONTINUE
C
C  NOW CALCULATE "G" FOR COCHRAN'S TEST
C
      DO 110 I=1,N
      SUMDEV = SUMDEV + TSDEV(I)
  110 CONTINUE
      WRITE(LW,310)SHI,SUMDEV
      COCRNG = SHI/SUMDEV
C
C  NOW CALCULATE ONE-WAY ANALYSIS OF VARIANCE INFORMATION
C
      STRT = 0.0
      DO 120 I=1,N
      STRT = STRT + (TRT(I)**2)
  120 CONTINUE
      SSTRT = (STRT/ANG) - CON
      SSE = SST - SSTRT
      DFTRT = AN-1.
      DFTOT = AN*ANG-1.
      DFBLK = ANG-1.
      DFERR = AN * DFBLK
      AMSTRT = SSTRT/DFTRT
      AMSE = SSE/DFERR
      F = AMSTRT/AMSE
C
C  NOW CALCULATE TWO-WAY ANALYSIS OF VARIANCE RESULTS
C
      SBLK = 0.0
      DO 130 J=1,NG
      SBLK =SBLK + (BLK(J)**2)
  130 CONTINUE
      SSBLK = (SBLK/AN)-CON
      SSE2 = SST - (SSTRT+SSBLK)
      DFE2 = DFTRT*DFBLK
      AMSBLK = SSBLK/DFBLK
      AMSE2 = SSE2/DFE2
      F2TRT = AMSTRT/AMSE2
      F2BLK = AMSBLK/AMSE2
C
C  NOW PRINT OUT RESULTS
C
      WRITE(LW,200)
      WRITE(LW,210)
      WRITE(LW,220)DFTRT,SSTRT,AMSTRT,F
      WRITE(LW,240)DFERR,SSE,AMSE
      WRITE(LW,250)DFTOT,SST
      WRITE(LW,260)COCRNG,N,NG
      WRITE(LW,270)
      WRITE(LW,280)
      WRITE(LW,210)
      WRITE(LW,220)DFTRT,SSTRT,AMSTRT,F2TRT
      WRITE(LW,230)DFBLK,SSBLK,AMSBLK,F2BLK
      WRITE(LW,240)DFE2,SSE2,AMSE2
      WRITE(LW,250)DFTOT,SST
      RETURN
C
C  FORMATS FOR PRINTOUT
C
  200 FORMAT(1H0,13X,'ONE-WAY ANALYSIS OF VARIANCE RESULTS'//10X,'NULL H
     1YPOTHESIS = ALL TREATMENT MEANS EQUAL'/10X,'ALTERNATE HYPOTH. = AL
     2L TREATMENT MEANS NOT EQUAL')
  210 FORMAT(1H0,19X,'DEGREES',7X,'SUM',10X,'MEAN'/6X,'SOURCE',10X,'OF',
     111X,'OF',9X,'SQUARE',9X,'F'/20X,'FREEDOM',5X,'SQUARES')
  220 FORMAT(1H0,'SAMPLE POSITION',5X,F4.0,5X,F11.3,3X,F10.3,3X,F7.3)
  230 FORMAT(1H0,'CAST./FORG. NO.',5X,F4.0,5X,F11.3,3X,F10.3,3X,F7.3)
  240 FORMAT(1H0,'ERROR',15X,F4.0,5X,F11.3,3X,F10.3)
  250 FORMAT(1H0,'TOTAL',15X,F4.0,5X,F11.3,///)
  260 FORMAT(1H0,47HCOCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" =,F7.4
     1,3X,'N = ',I2,3X,'K = ',I3)
  270 FORMAT(1H0,'NULL HYPOTH. = ALL BLOCK     VARIANCES ARE EQUAL '/1X,
     1'ALT. HYPOTH. = ALL BLOCK  VARIANCES ARE NOT EQUAL'///)
  280 FORMAT(1H0,13X,'TWO-WAY ANALYSIS OF VARIANCE RESULTS'//,10X,'NULL
     1HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL'/29X,'2) ALL BLOCK M
     2EANS ARE EQUAL'//10X,'ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE
     3NOT EQUAL'/30X,'2) ALL BLOCK MEANS ARE NOT EQUAL')
  290 FORMAT(1H1,'TREATMENT',6X,'TOTAL',9X,'MEAN,'6X,'SUM SQR DIFF',3X,'
     1STANDARD DEV'/)
  300 FORMAT(1H ,I3,1X,'(',A4,')',4X,F10.2,3X,F10.2,4X,F10.2,5X,F10.2)
  310 FORMAT(1H0,'HIGH STD.DEV. = ',F10.2,3X,'TOTAL ALL TREAT. STD. DEVS
     1. = ',F10.2//)
      END
```

```
      SUBROUTINE VALPLT(HI1,SML1,NG)
C
C  THIS SUBROUTINE IS DESIGNED TO PLOT TEST RESULTS FROM MULTIPLE
C   POSITIONS ON EACH CASTING OR FORGING, IF THIS SITUATION EXISTS.
C    THE LABEL PUT ON EACH PLOTTED POINT CORRESPONDS TO THE POSITION
C     WITHIN THE FORGING/CASTING FROM WHICH THE TEST SAMPLE WAS TAKEN.
C
      COMMON/UINPUT/LR,LW,FMT(19),TITLE(19),PNUM(19),FMT2(19)
      COMMON/PLOT1/UCL,BCL,RBAR,UCLL,BCLL,TMIN,N
      COMMON/STAT2/X(10),NSER(403),SSDEV,COMP(55,5),HOLD(11,403)
      COMMON/VALUE1/LABEL(11),DIV1,SP1(4)
      DIMENSION MON(11),NAME(14),LINE(101)
      DATA NAME/' ','-','.','4','*','3','4','5','7'/
      MOD(K)=K-(K/10)*10
      IF(NG.GT.15)WRITE(LW,105)
      WRITE(LW,100)TITLE
      WRITE(LW,110)PNUP
      WRITE(LW,112)
      WRITE(LW,113)
       SML1=SML1-5.
       SP1(1)=SML1
      SPOT=SML1+(DIV1*2.0)
       SP1(2)=SML1+(DIV1*0.5)
      SP1(3)=SML1+(DIV1)
      SP1(4)=SML1+(DIV1*1.5)
      WRITE(LW,115)SP1,SPOT
       DO 90 J=1,NG
        I=J-1
       DO 10 K=1,101
   10 LINE(K)=NAME(1)
        IF(MOD(I)) 25,15,25
   15 DO 20 K=1,101
   20 LINE(K)=NAME(2)
   25 DO 30 K=1,101,25
   30 LINE(K)=NAME(3)
C
C THE PREVIOUS STATEMENTS HAVE SET UP THE TITLE OF THE PLOT
C AND SOME OF THE SCALE FACTORS.  NOW WE DETERMINE THE PLOT POINTS.
C
C FIRST POINT
C
      MON(1)=((TMIN-SML1)/(DIV1*2.0))*100.+1.5
      LINE(MON(1))=NAME(4)
C
C NOW DETERMINE  OTHER POINTS
C
      NT=N+1
      DO 35 ILK=2,NT
      AMEN=((HOLD(ILK,J)-SML1)/(DIV1*2.0))*100.+1.5
      MON(ILK)=AMEN
      LINE(MON(ILK))=NAME(ILK+4)
   33 IF(MON(ILK).LE.100)GO TO 34
      MON(ILK)=101
      LINE(MON(ILK))=NAME(5)
   34 IF(MON(ILK).GE.1)GO TO 35
      MON(ILK)=1
      LINE(MON(ILK))=NAME(5)
   35 CONTINUE
C
C NOW PLOT THE POINTS
C
      WRITE(LW,95)HOLD(1,J),LINE
   90 CONTINUE
   95 FORMAT(1X,F6.0,3X,101A1)
      WRITE(LW,90)
   90 FORMAT(1H0,//,9X,'NOTE:  1) MISSING NUMBERS INDICATE DUPLICATION.'
     1/19X,'CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.'
     2//16X,'2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.')
      RETURN
  100 FORMAT(1H0,19A4)
  105 FORMAT(1H1)
  110 FORMAT(1H0,'VALUE PLOT:'/15X,'(SERIAL NUMBER VS. INDIVIDUAL TEST M
     1EASUREMENTS)'//30X,'PART NUMBER: ',19A4)
  112 FORMAT(1H0,45X,'NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER'/60X
     1,'(I.E., 3 =  TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING')
  113 FORMAT(1H0,'SERIAL',36X,'INDIVIDUAL TEST MEASUREMENTS'/1X,'NUMBER'
     1)
  115 FORMAT(1H0,1X,4(F12.3,13X),F12.3)
      END
```

```
C    MAIN PROGRAM
C
C   THIS PROGRAM WILL CALCULATE THE "T" STATISTIC FOR PAIRED OBSERVATIONS
C   THAT ARE NORMALLY DISTRIBUTED AND WILL ALSO YIELD THE DIFFERENCES FOR
C   EACH PAIR FOR THE NON-PARAMETRIC WILCOXON PAIRED T-TEST.
C
        DIMENSION DIFF(400),DIF2(400),DATE(7),PNUM(24)
C
C   READ IN DESCRIPTIVE VALUES CONCERNING DATA
C
    10 READ(5,20)NG,DMU
    20 FORMAT(I4,F10.2)
        IF(NG.EQ.0)GO TO 300
C
C ANG=NG= THE NUMBER OF DATA PAIRS
C DMU = THE VALUE TO BE INVESTIGATED BY THE HYPOTHESIS:HO: U1-U2 = DMU
C VALCRT = THE VALUE (AVERAGE) DETERMINED FROM MANUFACTURER'S TESTS.
C VALCMR = THE VALUE (AVERAGE) DETERMINED FROM ARC CO. TESTING
C DIFF(I) = THE DIFFERENCE BETWEEN VALCRT AND VALCMR
C DIF2(I) = THE DIFFERENCE (DIFF(I)) SQUARED
C SUMDIF = THE SUM OF THE DIFFERENCES
C SQRDIF = SUM OF THE DIFFERENCES SQUARED
C SDD = STANDARD DEVIATION OF THE DIFFERENCES
C DAVG = THE AVERAGE DIFFERENCE
C SDSQR = THE SAMPLE VARIANCE OF THE DIFFERENCES
C TSTAR = THE "T" STATISTIC FOR INVESTIGATING HO: THE NULL HYPOTH.
C NDOF = THE NUMBER OF DEGREES OF FREEDOM.
C
C INITIALIZATION
C
        DO 30 I=1,NG
        DIFF(I)=0.0
        DIF2(I)=0.0
    30 CONTINUE
        ANG = NG
        NDOF = NG - 1
        SUMDIF = 0.0
        SQRDIF = 0.0
C
C   BEGIN CALCULATION AND PRINT-OUT DATA AND RESULTS
C
        READ(5,175)DATE
        READ(5,190)PNUM
        WRITE(6,205)PNUM,DATE
        WRITE(6,206)
        DO 90 I=1,NG
        READ(5,200)SAMPR,VALCRT,VALCMR
        DIFF(I) = VALCRT-VALCMR
        SUMDIF = SUMDIF+DIFF(I)
        DIF2(I) = ABS(DIFF(I))**2
        SQRDIF = SQRDIF+DIF2(I)
        WRITE(6,201)SMPBR,VALCRT,VALCMR,DIFF(I),DIF2(I)
    90 CONTINUE
        WRITE(6,202)SUMDIF,SQRDIF
        SDSQR = ((ANG*SQRDIF)-(SUMDIF**2))/(ANG*(ANG-1.))
        SDD = SQRT(ABS(SDSQR))
        DAVG = SUMDIF/ANG
        TSTAR = (DAVG-DMU)/(SDD/(SQRT(ANG)))
        WRITE(6,203)SDSQR,SDD,DAVG,NDOF
        WRITE(6,204)TSTAR
        GO TO 10
C
C FORMAT STATEMENTS FOLLOW
C
   175 FORMAT(7A4)
   190 FORMAT(24A1)
   200 FORMAT(I5,2F10.3)
   201 FORMAT(1H0,I5,5X,F10.3,5X,F10.3,3X,F9.4,3X,F9.4)
   202 FORMAT(1H0,'TOTAL',33X,F9.4,2X,F10.4//)
   203 FORMAT(1H0,'SAMPLE VARIANCE = ',F10.3,3X,'SAMPLE STANDARD DEV. = '
      1,F10.2,3X,'AVERAGE DIFFERENCE = ',F7.4,3X,'DEG. OF FREEDOM = ',I3/
      2)
   204 FORMAT(1H0,'THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE T
      1WO TESTING MEANS = ',F7.4/10X,'NULL HYPOTH.:  U1-U2 = DMU'/10X,'AL
      2T. HYPOTH.:  U1-U2.NE.DMU'//10X,'ASSUMPTION:  THE DISTRIBUTION UND
      3ERLYING THE DIFFERENCES IS NORMAL.')
   205 FORMAT(1H1,'DETERMINATION OF A DIFFERENCE IN TESTING FOR'/20X,'PAR
      1T NUMBER:  ',24A1,'TESTING VS. ARC CO. TESTING'/40X,'DATA FROM ',7
      2A4//)
   206 FORMAT(1H0,'SER.NO.',4X,'CERT DATA',6X,'CMR DATA'5X,'DIFFERENCE',2
      1X,'DIFF.SQRD'/)
   300 STOP
        END
```

APPENDIX E

APPENDIX E

**ROOM TEMP.TENSILE TESTS-ULTIMATE LAC.PAC.(1/77 TO 5/79) CERT CATA

--3072112--TFE731 ENGINE PART

12 4 0 0 0

FORMAT(I5,4F10.2)

FORMAT(4A4)

POS3POS4POS5POS7

SERIAL #	INPUT CATA BY POSITION			
2237	191.50	190.30	185.50	190.70
2164	190.90	191.40	195.80	194.70
395	192.00	193.90	184.40	191.50
2382	198.40	200.80	197.60	195.50
404	197.60	190.10	198.00	196.40
2374	196.40	195.20	208.90	196.00
3015	195.20	196.00	190.90	198.00
3345	176.30	175.50	176.80	148.70
8800	193.60	195.20	196.40	193.60
3040	193.30	193.30	198.00	192.90
3046	200.00	201.60	189.30	202.40
3010	208.40	206.80	206.70	204.80

THE MEAN = 193.69 STANC CEV = 9.76

SUM = 9297.20 SUM OF SQUARES =1805270.84

TREATMENT	TOTAL	MEAN.	SUM SQR DIFF	STANDARD DEV
1 (POS3)	2333.60	194.47	614.07	55.92
2 (POS4)	2330.10	194.17	652.76	59.34
3 (POS5)	2328.30	194.02	929.20	84.47
4 (POS7)	2305.20	192.10	2242.95	203.91

HIGH STD.DEV. = 203.91 TOTAL ALL TREAT. STD. DEVS.=403.55

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	41.750	13.917	.138
ERROR	44.	4439.062	100.888	
TOTAL	47.	4480.812		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .5053 N = 4
NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL K = 12
ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
2) ALL BLOCK MEANS ARE EQUAL
ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	41.750	13.917	.474
CAST./FORG. NO.	11.	3469.828	315.439	10.740
ERROR	33.	969.234	29.371	
TOTAL	47.	4480.812		

3072112
CERT CATA

3 SIGMA-

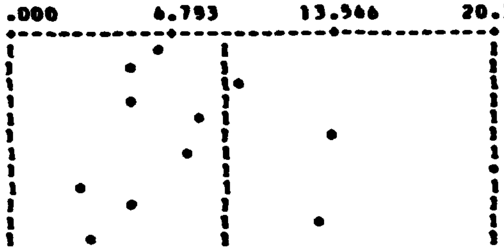
RANGE CHART

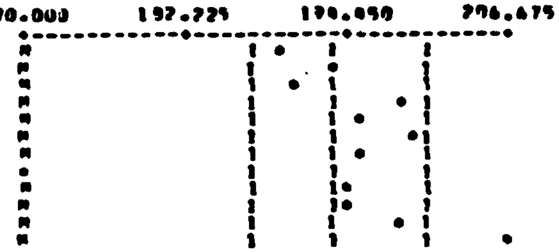
LCL= .0000
CENTER= 9.9250
UCL= 20.3496

X-BAR CHART

LCL= 187.1764
CENTER= 193.6917
UCL= 200.2069

RANGE	SERIAL NUMBER	X-BAR
6.000	2237	197.500
4.900	2164	193.200
9.500	395	190.450
5.300	2392	195.075
7.900	404	195.525
13.700	2374	199.125
7.100	93015	195.025
20.100	93345	169.325
2.900	99500	194.700
5.100	3040	194.375
13.100	3046	195.325
3.600	3010	206.675





2 SIGMA-

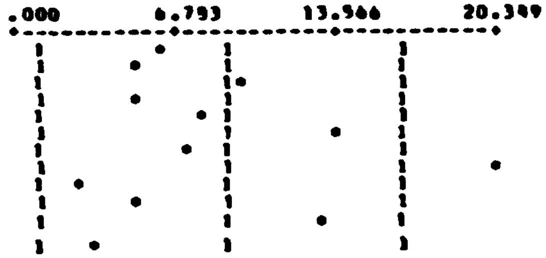
RANGE CHART

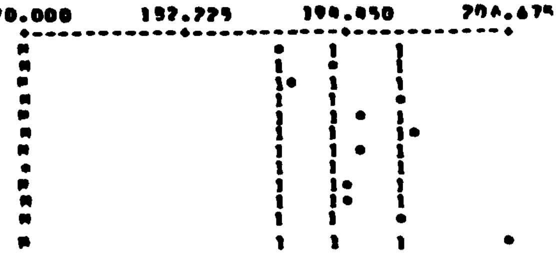
LCL= 1.2799
CENTER= 8.9250
UCL= 16.5360

X-BAR CHART

LCL= 189.3482
CENTER= 193.6917
UCL= 198.0352

RANGE	SERIAL NUMBER	X-BAR
6.000	2237	199.500
4.900	2164	193.200
9.500	395	190.450
5.300	2392	195.075
7.900	404	195.525
13.700	2374	199.125
7.100	93015	195.025
20.100	93345	169.325
2.900	99500	194.700
5.100	3040	194.375
13.100	3046	195.325
3.600	3010	206.675





1 SIGMA-

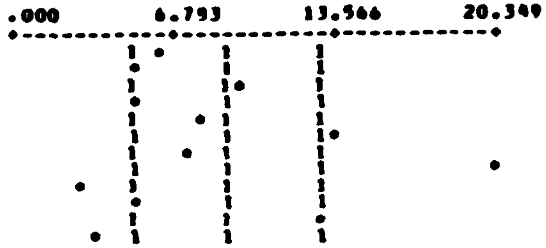
RANGE CHART

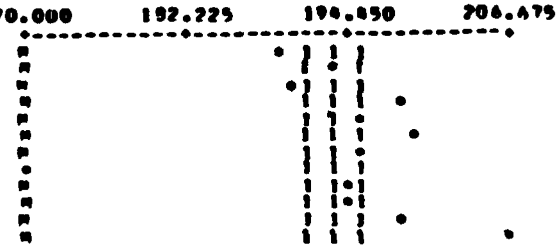
LCL= 5.1129
CENTER= 8.9250
UCL= 12.7239

X-BAR CHART

LCL= 191.5199
CENTER= 193.6917
UCL= 195.8634

RANGE	SERIAL NUMBER	X-BAR
6.000	2237	199.500
4.900	2164	193.200
9.500	395	190.450
5.300	2392	195.075
7.900	404	195.525
13.700	2374	199.125
7.100	93015	195.025
20.100	93345	169.325
2.900	99500	194.700
5.100	3040	194.375
13.100	3046	195.325
3.600	3010	206.675





**ROOM TEMP. TENSILE TESTS-ULTIMATE LAC-PACIFIC(1/77 TO 10/78)CMR CATA
--3072112--TFE731 ENGINE PART
14 3 0 0 0
FORMAT(I5,3F10.2)
FORMAT(3A4)
POS3POS4POS5

SERIAL #		INPUT CATA BY POSITION	
2164	192.10	193.30	190.20
395	192.70	191.00	189.40
2382	196.10	191.40	192.90
2361	194.50	196.20	192.10
3004	193.43	194.90	193.10
3443	198.00	195.70	192.30
1011	196.90	194.10	195.30
1048	196.50	197.50	193.90
800	206.10	203.30	202.70
3337	196.30	195.10	193.90
3368	194.90	194.90	192.00
3040	192.70	195.30	193.80
3046	200.80	201.60	200.60
3010	205.50	204.70	204.90

THE MEAN = 196.01 STANC CEV = 4.39
SUM = 8232.63 SUM OF SQUARES =1614509.44

TREATMENT	TOTAL	MEAN.	SUM SQR DIFF	STANDARD DEV.
1 (POS3)	2756.53	196.89	256.30	19.72
2 (POS4)	2749.00	196.36	221.71	17.05
3 (POS5)	2727.10	194.79	279.13	21.47

HIGH STD.DEV. = 21.47 TOTAL ALL TREAT. STD. DEVS. =58.24

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	33.344	16.672	.859
ERROR	39.	757.219	19.416	
TOTAL	41.	790.562		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3697 K = 14

NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 3
ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
2) ALL BLOCK MEANS ARE NOT EQUAL

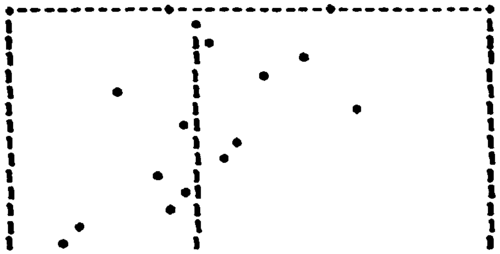
SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	33.344	16.672	9.520
CAST./FORG. NO.	13.	711.687	54.745	31.261
ERROR	26.	45.531	1.751	
TOTAL	41.	790.562		

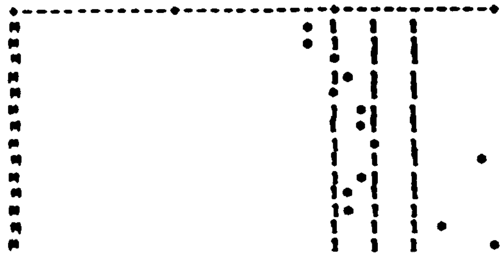
3072112 CHR DATA

3 SIGMA-

RANGE CHART — LCL= .0000 CENTER= 3.0143 UCL= 7.7467

X-BAR CHART — LCL= 192.9804 CENTER= 196.0150 UCL= 199.0496



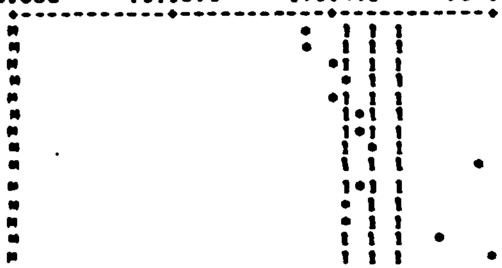


CHR DATA	SERIAL NUMBER	
3.100	2164	191.967
3.300	395	191.033
4.700	2392	193.467
4.100	2361	194.267
1.900	3004	193.910
5.700	3443	195.333
2.900	1011	195.433
3.600	1049	195.967
3.400	900	204.033
2.400	3337	195.100
2.900	3369	193.933
2.600	3040	193.933
1.000	3046	201.000
.800	3010	205.033

2 SIGMA-

RANGE CHART — LCL= .0000 CENTER= 3.0143 UCL= 6.1593

X-BAR CHART — LCL= 193.9653 CENTER= 196.0150 UCL= 199.0647

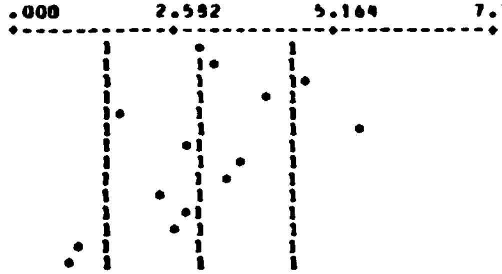


	SERIAL NUMBER	
3.100	2164	191.967
3.300	395	191.033
4.700	2392	193.467
4.100	2361	194.267
1.900	3004	193.910
5.700	3443	195.333
2.900	1011	195.433
3.600	1049	195.967
3.400	900	204.033
2.400	3337	195.100
2.900	3369	193.933
2.600	3040	193.933
1.000	3046	201.000
.900	3010	205.033

1 SIGMA-

RANGE CHART — LCL= 1.4269 CENTER= 3.0143 UCL= 4.5719

X-BAR CHART — LCL= 194.9931 CENTER= 196.0150 UCL= 197.0399



	SERIAL NUMBER	
3.100	2164	191.967
3.300	395	191.033
4.700	2392	193.467
4.100	2361	194.267
1.900	3004	193.910
5.700	3443	195.333
2.900	1011	195.433
3.600	1049	195.967
3.400	900	204.033
2.400	3337	195.100
2.900	3369	193.933
2.600	3040	193.933
1.000	3046	201.000
.900	3010	205.033

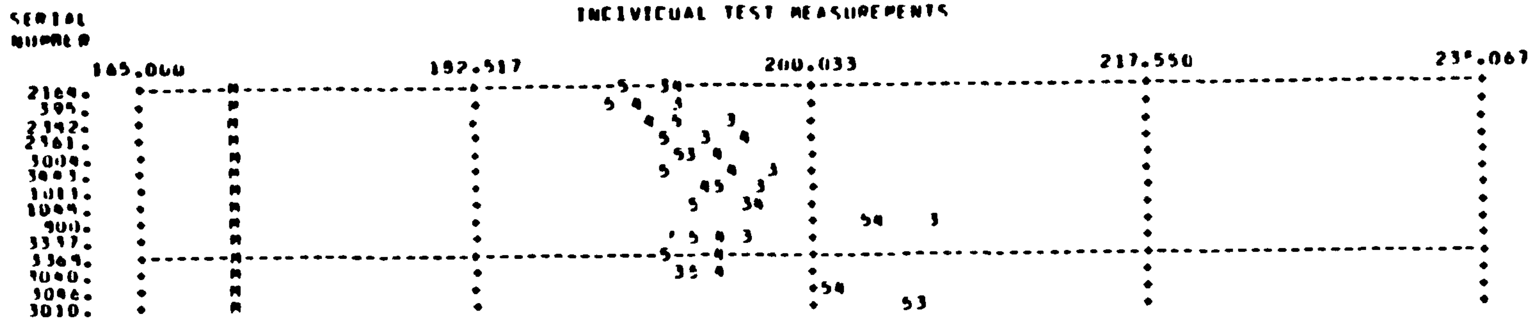
**ROOM TEMP. TENSILE TESTS-ULTIMATE LAC-PACIFIC(1/77 TO 10/79)CMR DATA

VALUE PLOT:

(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--TFE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E.. 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING



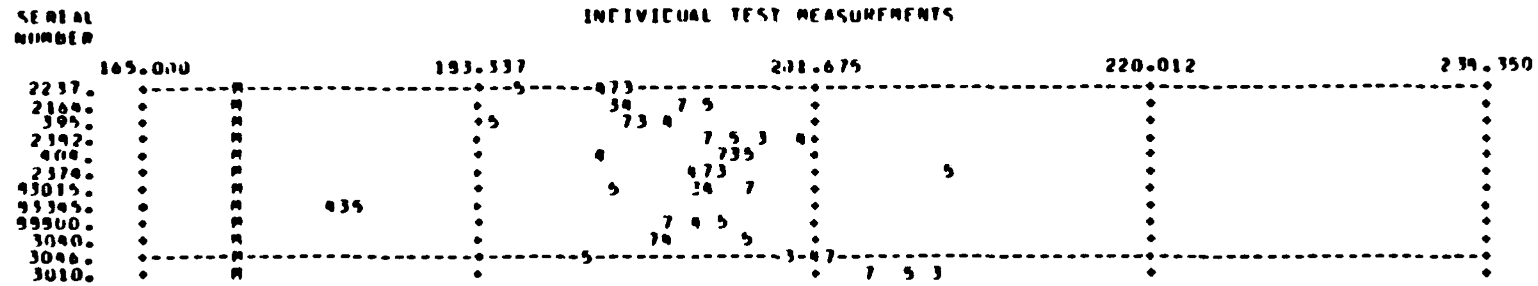
**ROOM TEMP.TENSILE TESTS-ULTIMATE LAC.PAC.(1/77 TO 5/79) CERT DATA

VALUE PLOT:

(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)

PART NUMBER: --3072112--TFE731 ENGINE PART

NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E.. 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING



NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.
2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

DETERMINATION OF A CIFFERENCE IN TESTING FOR
PART NUMBER: 3072112 LACISH PACIFIC TESTING VS. ARC CO. TESTING
CATA FROM 1/77 TO 5/79 (ULTIMATE)

SER.NO.	CERT CATA	CMR CATA	CIFFERENCE	CIFF.SORC
2164	193.200	191.867	1.3330	1.7769
395	190.450	191.033	-.5830	.3399
2392	198.075	193.467	4.6080	21.2337
82374	199.125	194.267	4.8580	23.6002
93015	195.025	193.810	1.2150	1.4762
83345	169.325	195.333	-26.0080	676.4160
98800	194.700	204.033	-9.3330	87.1049
3040	194.375	193.933	.4420	.1954
3046	198.325	201.000	-2.6750	7.1556
3010	206.675	205.033	1.6420	2.6962
TOTAL			-24.5010	821.9949

AVERAGE CIFFERENCE = -2.4501 CEG. OF FREECOM = 9

SAMPLE VARIANCE = 84.663 SAMPLE STANCARC CEV. = 9.20

THE "T." STATISTIC FOR TESTING THE CIFFERENCE IN THE TWO TESTING MEANS = -.8420
NULL HYPOTH.: U1-U2 = CMU
ALT. HYPOTH.: U1-U2.NE.CMU

ASSUMPTION: THE CISTRIBUTION UNCERLYING THE CIFFERENCES IS NORMAL.

**ROOM TEMP.TENSILE TESTS-%ELONG.LAC.PAC.(1/77 TO 5/79)CERT DATA
--3072112--TFE731 ENGINE PART
12 4 0 0 0
FORMAT(I5,4F10.2)
FORMAT(4A4)
POS3POS4POS5POS7

SERIAL # INPUT DATA BY POSITION

2237	17.00	17.00	17.00	12.00
2164	21.30	20.00	20.00	22.00
395	23.00	23.00	15.00	23.00
2382	20.00	18.00	20.00	16.00
404	20.00	14.00	26.00	23.00
2374	19.00	15.00	18.00	19.00
3015	24.00	24.00	20.00	23.00
3345	12.00	12.00	13.00	4.00
9800	19.00	21.00	20.00	19.00
3040	22.00	22.00	22.00	20.00
3046	26.00	24.00	16.00	25.00
3010	13.00	21.00	21.00	24.00

THE MEAN = 19.28 STAND DEV = 4.39
SUM = 925.30 SUM OF SQUARES = 18741.69

TREATMENT	TOTAL	MEAN.	SUM SQR DIFF	STANDARD DEV
1 (POS3)	236.30	19.69	189.55	17.23
2 (POS4)	231.00	19.25	178.25	16.20
3 (POS5)	228.00	19.00	132.00	12.00
4 (POS7)	230.00	19.17	401.67	36.52

HIGH STD.DEV. = 36.52 TOTAL ALL TREAT. STD. DEVS. =81.95

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	3.139	1.046	.051
ERROR	44.	901.466	20.488	
TOTAL	47.	904.605		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .4456 N = 4
NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL K = 12
ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
2) ALL BLOCK MEANS ARE NOT EQUAL

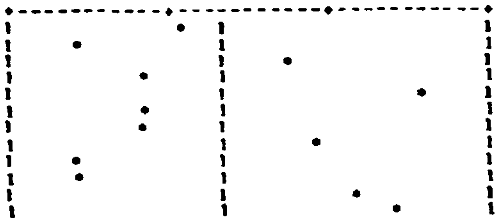
SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	3.139	1.046	.094
CAST./FORG. NO.	11.	535.637	48.694	4.393
ERROR	33.	365.829	11.086	
TOTAL	47.	904.605		

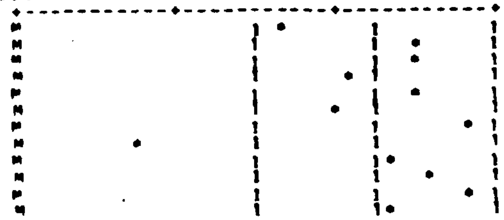
3072112
CERT DATA

3 SIGMA-

RANGE CHART
LCL= .0000 CENTER= 6.0933 UCL= 13.9700

X-BAR CHART
LCL= 14.8363 CENTER= 19.2771 UCL= 23.7179



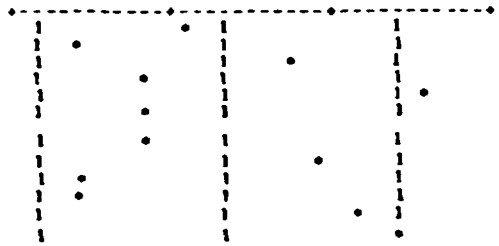


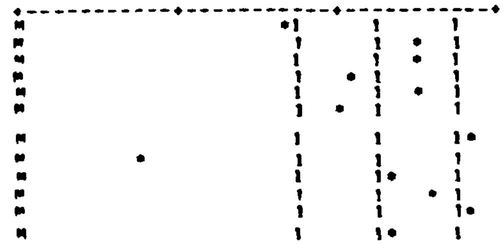
Range	Serial Number	X-bar
5.000	2237	15.750
2.000	2164	20.925
9.000	395	21.000
4.000	2392	19.500
12.000	404	20.750
4.000	2374	17.750
4.000	93015	22.750
9.000	93345	10.250
2.000	99900	19.750
2.000	3040	21.500
10.000	3046	22.750
11.000	3010	19.750

2 SIGMA-

RANGE CHART
LCL= .9559 CENTER= 6.0933 UCL= 11.2712

X-BAR CHART
LCL= 16.3165 CENTER= 19.2771 UCL= 22.2376



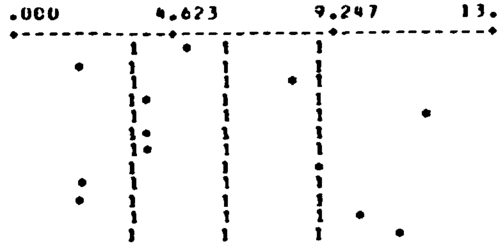


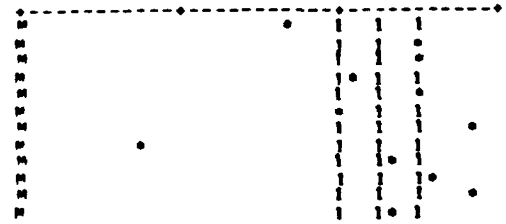
Range	Serial Number	X-bar
5.000	2237	15.750
2.000	2164	20.925
9.000	395	21.000
4.000	2392	19.500
12.000	404	20.750
4.000	2374	17.750
4.000	93015	22.750
9.000	93345	10.250
2.000	99900	19.750
2.000	3040	21.500
10.000	3046	22.750
11.000	3010	19.750

1 SIGMA-

RANGE CHART
LCL= 3.4946 CENTER= 6.0933 UCL= 8.6726

X-BAR CHART
LCL= 17.7969 CENTER= 19.2771 UCL= 20.7574





Range	Serial Number	X-bar
5.000	2237	15.750
2.000	2164	20.925
9.000	395	21.000
4.000	2392	19.500
12.000	404	20.750
4.000	2374	17.750
4.000	93015	22.750
9.000	93345	10.250
2.000	99900	19.750
2.000	3040	21.500
10.000	3046	22.750
11.000	3010	19.750

**ROOM TEMP.TENSILE TESTS-%ELONG LAC-PACIFIC(1/77 TO 10/79) CMR DATA
--3072112--TFE731 ENGINE PART

14	3	0	0	0

FORMAT(I5,3F10.2)
FORMAT(3A4)
POS3POS4POS5

SERIAL #	INPUT DATA BY POSITION		
2164	19.50	21.20	19.90
395	21.60	20.70	20.70
2392	16.20	16.90	19.40
2361	19.40	21.90	20.90
3004	22.47	22.90	21.50
3443	22.70	23.20	22.20
1011	22.90	22.90	22.80
1049	21.30	22.50	21.90
900	25.00	22.50	23.90
3337	22.70	25.70	24.00
3369	22.00	24.20	24.70
3040	21.00	23.60	24.60
3046	21.60	25.50	25.50
3010	21.40	22.90	26.00

THE MEAN = 22.16 STAND DEV = 2.26
SUM = 930.67 SUM OF SQUARES = 20831.30

TREATMENT	TOTAL	MEAN,	SUM SQR DIFF	STANDARD DEV
1 (POS3)	298.77	21.34	59.75	4.60
2 (POS4)	316.20	22.59	61.98	4.77
3 (POS5)	315.70	22.55	72.97	5.61

HIGH STD.DEV. = 5.61 TOTAL ALL TREAT. STD. DEVS. =14.98

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	14.064	7.032	1.409
ERROR	39.	194.698	4.992	
TOTAL	41.	208.763		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3748 K = 14
NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 3
ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

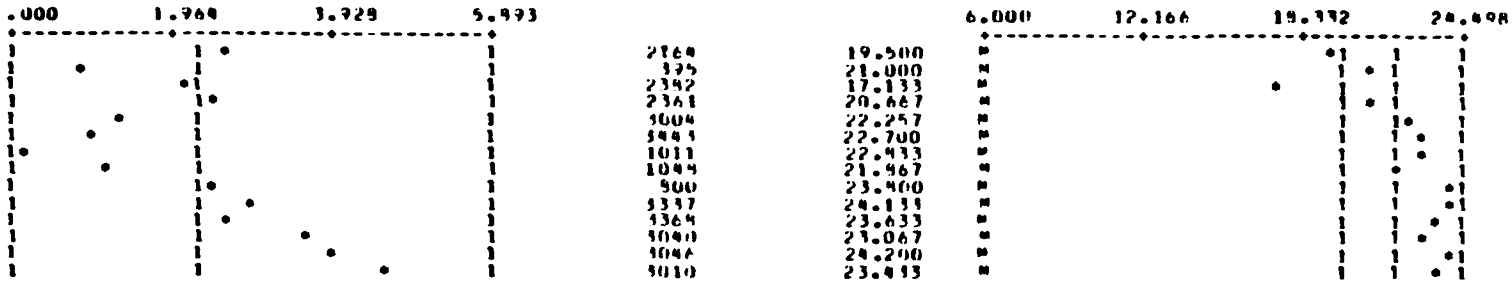
TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
2) ALL BLOCK MEANS ARE EQUAL
ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	14.064	7.032	4.769
CAST./FORG. NO.	13.	156.356	12.027	8.156
ERROR	26.	38.342	1.475	
TOTAL	41.	208.763		

3072112
CMR DATA

LCL= .0000 CENTER= 2.2929 UCL= 5.8926 RANGE CHART	3 SIGMA-	LCL= 19.8231 CENTER= 22.1588 UCL= 24.4975 X-BAR CHART



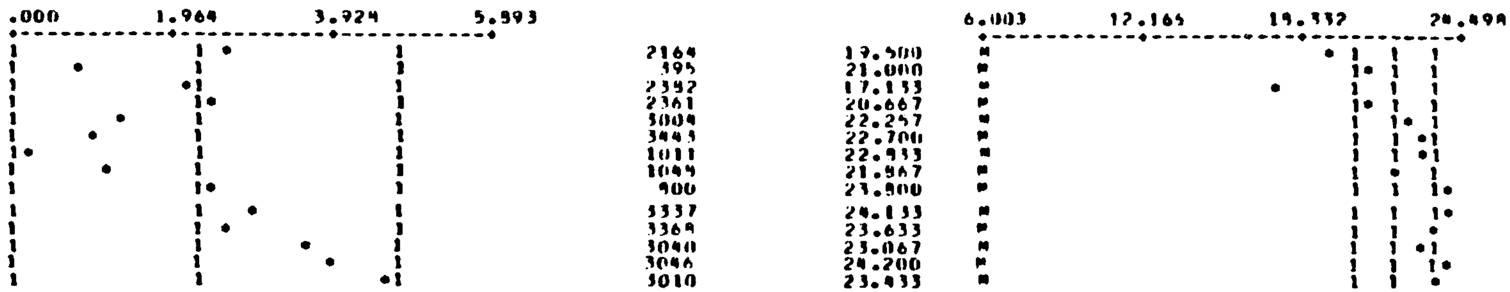
Range	Serial Number	X-bar
2.700	2164	19.500
.900	395	21.000
2.200	2392	17.133
2.400	2361	20.667
1.300	3004	22.257
1.000	3443	22.700
.100	1011	22.933
1.200	1049	21.967
2.500	900	23.900
3.000	3337	24.133
2.700	3369	23.633
3.600	3040	23.067
3.900	3046	24.200
4.600	3010	23.433

RANGE CHART 2 SIGMA- X-BAR CHART

LCL= .0000 CENTER= 2.2929 UCL= 4.6952

SERIAL NUMBER

LCL= 20.5997 CENTER= 22.1589 UCL= 23.7180



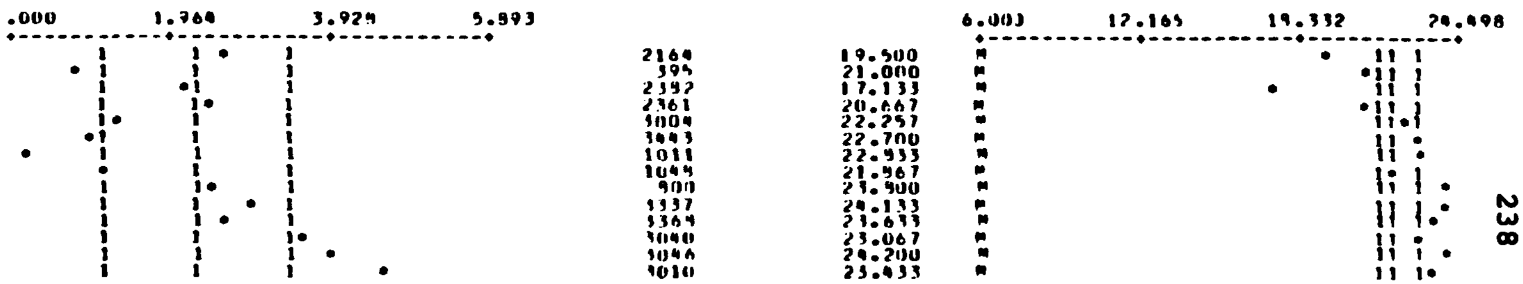
Range	Serial Number	X-bar
2.700	2164	19.500
.900	395	21.000
2.200	2392	17.133
2.400	2361	20.667
1.300	3004	22.257
1.000	3443	22.700
.100	1011	22.933
1.200	1049	21.967
2.500	900	23.900
3.000	3337	24.133
2.700	3369	23.633
3.600	3040	23.067
3.900	3046	24.200
4.600	3010	23.433

RANGE CHART 1 SIGMA- X-BAR CHART

LCL= 1.0954 CENTER= 2.2929 UCL= 3.4777

SERIAL NUMBER

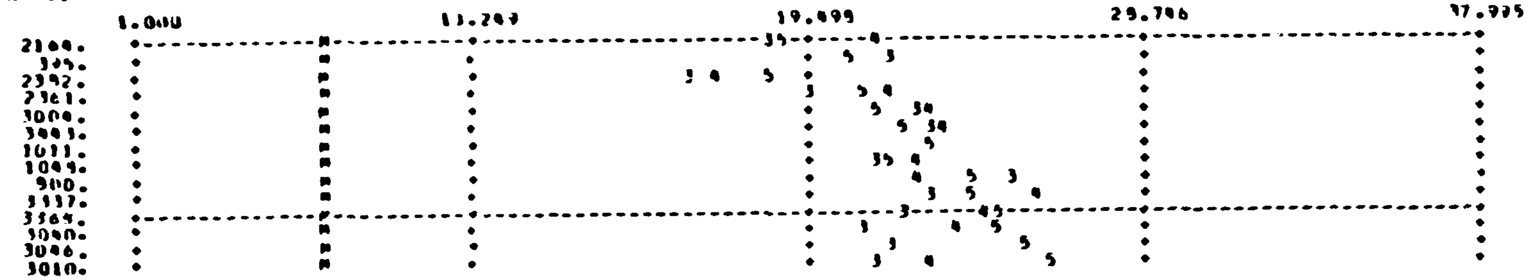
LCL= 21.3792 CENTER= 22.1589 UCL= 22.9384



Range	Serial Number	X-bar
2.700	2164	19.500
.900	395	21.000
2.200	2392	17.133
2.400	2361	20.667
1.300	3004	22.257
1.000	3443	22.700
.100	1011	22.933
1.200	1049	21.967
2.500	900	23.900
3.000	3337	24.133
2.700	3369	23.633
3.600	3040	23.067
3.900	3046	24.200
4.600	3010	23.433

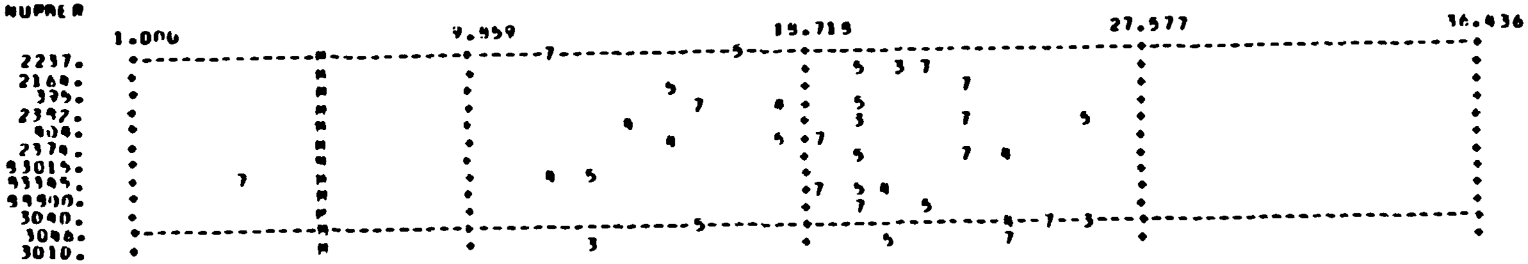
**ROOM TEMP.TENSILE TESTS-%ELONG LAC-PACIFIC(1/77 TO 10/79) CMR DATA

VALUE PLOT:
(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)
PART NUMBER: --3072112--TFE731 ENGINE PART
NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E.. 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING



**ROOM TEMP.TENSILE TESTS-%ELONG.LAC.PAC.(1/77 TO 5/79)CERT DATA

VALUE PLOT:
(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)
PART NUMBER: --3072112--TFE731 ENGINE PART
NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E.. 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING



NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.
2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

DETERMINATION OF A DIFFERENCE IN TESTING FOR
PART NUMBER: 3072112 LADISH PACIFIC TESTING VS. ARC CO. TESTING
DATA FROM 1/77 TO 5/79 (%ELONG. DATA)

SER.NO.	CERT DATA	CMR DATA	DIFFERENCE	DIFF.SQRD
2164	20.825	19.500	1.3250	1.7556
395	21.000	21.000	.0000	.0000
2392	18.500	17.133	1.3670	1.8687
92374	17.750	20.667	-2.9170	8.5089
93015	22.750	22.257	.4930	.2430
93345	10.250	22.700	-12.4500	155.0025
99800	19.750	23.800	-4.0500	16.4025
3040	21.500	23.067	-1.5670	2.4555
3046	22.750	24.200	-1.4500	2.1025
3010	19.750	23.433	-3.6830	13.5645
TOTAL			-22.9320	201.9037

AVERAGE DIFFERENCE = -2.2932 DEG. OF FREEDOM = 9

SAMPLE VARIANCE = 16.591 SAMPLE STANDARD DEV. = 4.07

THE "T." STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -1.7804
NULL HYPOTH.: U1-U2 = DMU
ALT. HYPOTH.: U1-U2.NE.DMU

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

**ROOM TEMP.TENSILE TESTS-%REC.AREA LAC.PAC.(1/77 TO 5/79)   CERT DATA
--3072112--TFE731 ENGINE PART
12 4 0 0 0
FORMAT(I5,4F10.2)
FORMAT(4A4)
POS3POS4POS5POS7

SERIAL #	INPUT DATA BY POSITION			
2237	18.20	18.20	18.20	16.00
2164	17.60	20.50	22.30	24.60
395	27.90	24.70	15.20	19.00
2382	23.10	16.70	21.00	18.30
404	22.40	13.10	26.70	20.30
2374	20.20	12.40	17.60	20.20
3015	22.30	23.70	21.50	24.00
3345	14.40	12.20	15.20	8.60
8900	17.50	19.50	18.80	18.20
3040	23.70	21.50	20.40	21.50
3046	29.20	22.60	18.90	29.20
3010	22.40	20.90	25.50	28.90

THE MEAN = 20.33   STAND DEV = 4.54
SUM = 975.80   SUM OF SQUARES = 20807.36

TREATMENT	TOTAL	MEAN,	SUM SQR CIFF	STANCARC CEV
1 (POS3)	258.90	21.57	204.04	18.55
2 (POS4)	226.00	18.83	210.11	19.10
3 (POS5)	241.20	20.10	141.69	12.89
4 (POS7)	249.70	20.81	365.47	33.22

HIGH STD.DEV. = 33.22 TOTAL ALL TREAT. STC. CEVS. =83.75

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	CEGREES OF FREECOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	48.861	16.287	.778
ERROR	44.	921.299	20.939	
TOTAL	47.	970.160		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .3967 N = 4

NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL n = 12
ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
2) ALL BLOCK MEANS ARE NOT EQUAL

SOURCE	CEGREES OF FREECOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	3.	48.861	16.287	1.332
CAST./FORG. NO.	11.	517.710	47.065	3.848
ERROR	33.	403.589	12.230	
TOTAL	47.	970.160		

3072112
CERT DATA

3 SIGMA-

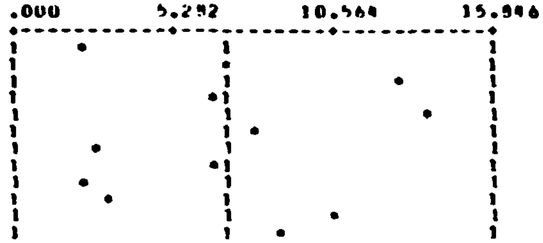
LCL= .0000
CENTER= 6.9500
UCL= 15.9466

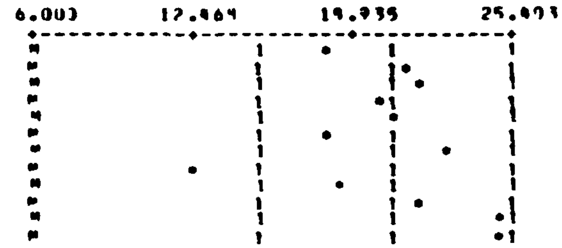
RANGE CHART

LCL= 15.2557
CENTER= 20.3292
UCL= 25.4027

X-BAR CHART

Range	Serial Number	X-bar
2.200	2237	17.650
7.000	2164	21.250
12.700	395	21.700
6.400	2392	19.775
13.600	404	20.625
7.900	2374	17.600
2.500	93015	22.975
6.600	93345	12.600
2.000	99900	19.500
3.300	3040	21.775
10.400	3046	24.950
9.900	3010	24.650





2 SIGMA-

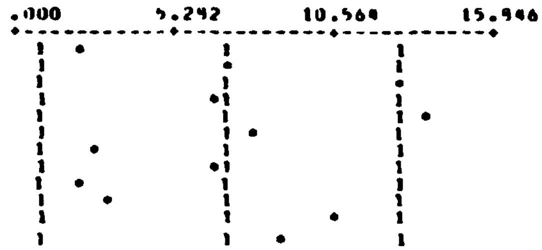
RANGE CHART

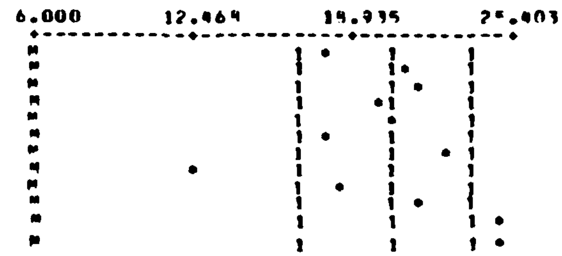
LCL= 1.0121
CENTER= 6.9500
UCL= 12.9771

X-BAR CHART

LCL= 16.9469
CENTER= 20.3292
UCL= 23.7115

Range	Serial Number	X-bar
2.200	2237	17.650
7.000	2164	21.250
12.700	395	21.700
6.400	2392	19.775
13.600	404	20.625
7.900	2374	17.600
2.500	93015	22.975
6.600	93345	12.600
2.000	99900	19.500
3.300	3040	21.775
10.400	3046	24.950
9.900	3010	24.650





1 SIGMA-

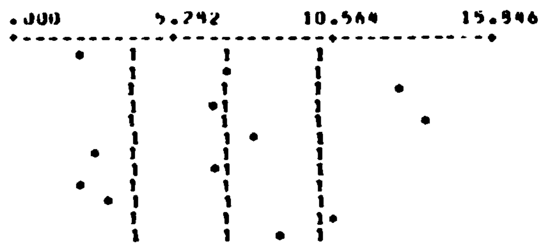
RANGE CHART

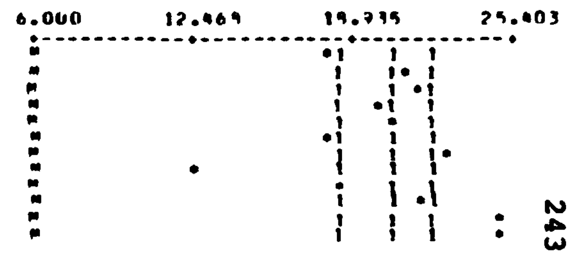
LCL= 3.9911
CENTER= 6.9500
UCL= 9.9091

X-BAR CHART

LCL= 19.6380
CENTER= 20.3292
UCL= 22.0203

Range	Serial Number	X-bar
2.200	2237	17.650
7.000	2164	21.250
12.700	395	21.700
6.400	2392	19.775
13.600	404	20.625
7.900	2374	17.600
2.500	93015	22.975
6.600	93345	12.600
2.000	99900	19.500
3.300	3040	21.775
10.400	3046	24.950
9.900	3010	24.650





**ROOM TEMP.TENSILE TESTS-%RED.AREA LAC-PACIFIC(1/77 TO 10/79) CMR DATA

--3072112--TFE731 ENGINE PART

14 3 0 0 0

FORMAT(I5,3F10.2)

FORMAT(3A4)

POS3POS4POS5

SERIAL #	INPUT DATA BY POSITION		
2164	19.00	17.50	18.60
395	22.60	21.50	20.10
2382	16.10	15.40	17.90
2361	20.80	21.80	22.90
3004	22.60	24.00	21.10
3443	24.00	25.40	22.90
1011	24.00	22.90	21.50
1045	24.40	20.80	24.00
900	26.70	26.00	24.40
3337	24.00	26.00	24.00
3365	20.40	26.30	24.40
3040	20.40	24.30	24.70
3046	20.40	26.70	24.00
3010	21.10	23.30	26.50

THE MEAN = 22.51 STAND DEV = 2.84

SUM = 945.40 SUM OF SQUARES = 21611.10

TREATMENT	TOTAL	MEAN.	SUM SQR DIFF	STANDARD DEV
1 (POS3)	306.50	21.89	94.15	7.24
2 (POS4)	321.90	22.99	147.67	11.36
3 (POS5)	317.00	22.64	79.93	6.15

HIGH STD.DEV. = 11.36 TOTAL ALL TREAT. STD. DEVS. =24.75

ONE-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = ALL TREATMENT MEANS EQUAL
ALTERNATE HYPOTH. = ALL TREATMENT MEANS NOT EQUAL

SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	8.844	4.422	.536
ERROR	39.	321.753	8.250	
TOTAL	41.	330.597		

COCHRAN'S EQUALITY OF VARIANCES STATISTIC "G" = .4590 K = 14

NULL HYPOTH. = ALL BLOCK VARIANCES ARE EQUAL N = 3
ALT. HYPOTH. = ALL BLOCK VARIANCES ARE NOT EQUAL

TWO-WAY ANALYSIS OF VARIANCE RESULTS

NULL HYPOTHESIS = 1) ALL TREATMENT MEANS ARE EQUAL
2) ALL BLOCK MEANS ARE EQUAL

ALTERNATE HYPOTH. = 1) ALL TREAT. MEANS ARE NOT EQUAL
2) ALL BLOCK MEANS ARE NOT EQUAL

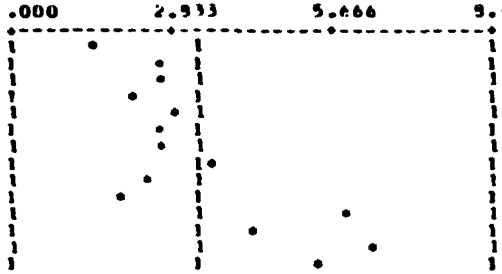
SOURCE	DEGREES OF FREEDOM	SUM OF SQUARES	MEAN SQUARE	F
SAMPLE POSITION	2.	8.844	4.422	1.293
CAST./FORG. NO.	13.	232.844	17.911	5.239
ERROR	26.	88.910	3.420	
TOTAL	41.	330.597		

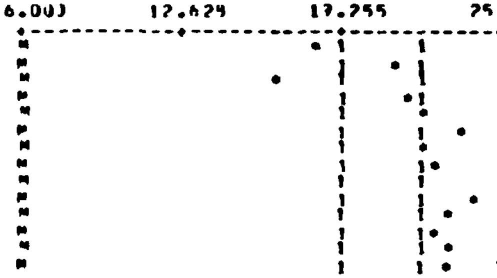
3072112
CMR DATA

LCL = .0000
CENTER = 3.3071
UCL = 9.4994
RANGE CHART

3 SIGMA-
SERIAL
NUMBER

LCL = 19.1362
CENTER = 22.5095
UCL = 25.8828
X-BAR CHART



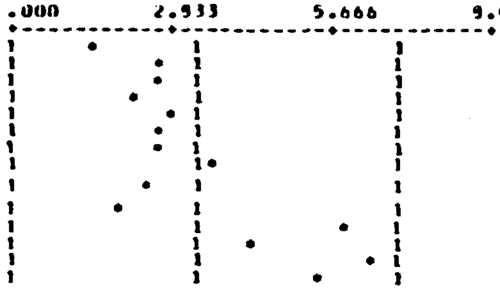


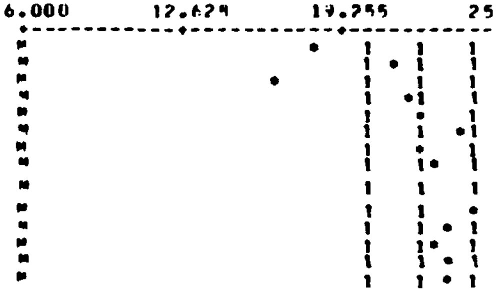
1.500	2164	19.367
2.500	395	21.400
2.500	2392	16.467
2.100	2361	21.933
2.900	3004	22.567
2.500	3443	24.100
2.500	1011	22.400
3.600	1049	23.067
2.300	900	25.700
2.000	3337	24.667
5.900	3369	23.700
4.300	3040	23.133
6.300	3046	23.700
5.400	3010	23.633

RANGE CHART
LCL = .0000
CENTER = 3.3071
UCL = 6.7577

2 SIGMA-
SERIAL
NUMBER

X-BAR CHART
LCL = 20.2637
CENTER = 22.5095
UCL = 24.7588



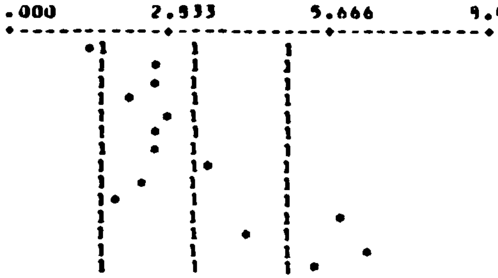


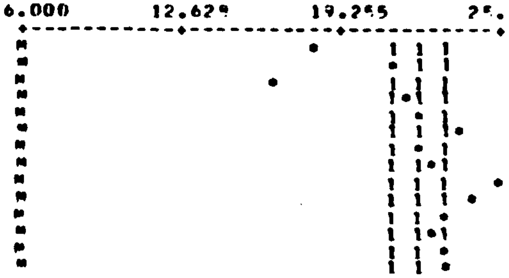
1.500	2164	19.367
2.500	395	21.400
2.500	2392	16.467
2.100	2361	21.933
2.900	3004	22.567
2.500	3443	24.100
2.500	1011	22.900
3.600	1049	23.067
2.300	900	25.700
2.000	3337	24.667
5.900	3369	23.700
4.300	3040	23.133
6.300	3046	23.700
5.400	3010	23.633

RANGE CHART
LCL = 1.5655
CENTER = 3.3071
UCL = 5.0161

1 SIGMA-
SERIAL
NUMBER

X-BAR CHART
LCL = 21.3951
CENTER = 22.5095
UCL = 23.6340

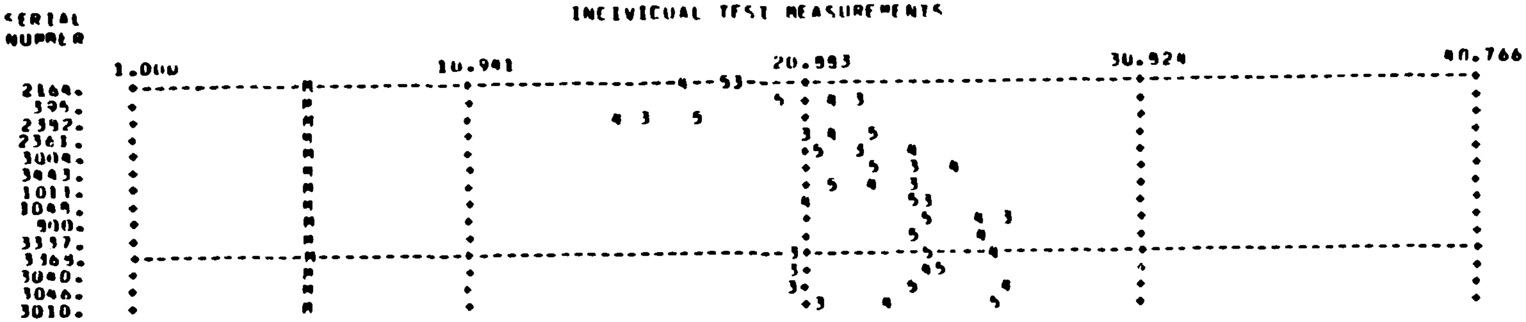




1.500	2164	19.367
2.500	395	21.400
2.500	2392	16.467
2.100	2361	21.933
2.900	3004	22.567
2.500	3443	24.100
2.500	1011	22.900
3.600	1049	23.067
2.300	900	25.700
2.000	3337	24.667
5.900	3369	23.700
4.300	3040	23.133
6.300	3046	23.700
5.400	3010	23.633

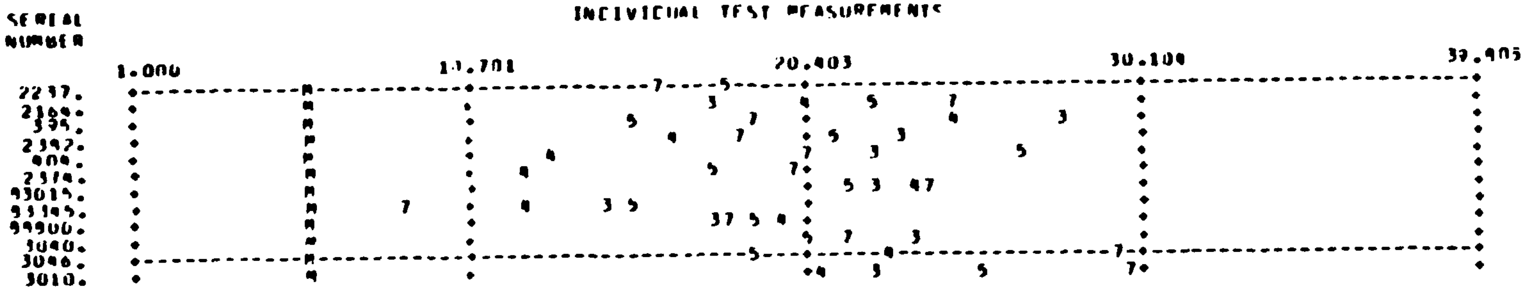
**ROOM TEMP.TENSILE TESTS-RFC.AREA LAC-PACIFIC(1/77 TO 10/79) CMR DATA

VALUE PLOT:
(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)
PART NUMBER: --3072112--TFE731 ENGINE PART
NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING



**ROOM TEMP.TENSILE TESTS-RFC.AREA LAC.PAC.(1/77 TO 5/79) CERT DATA

VALUE PLOT:
(SERIAL NUMBER VS. INDIVIDUAL TEST MEASUREMENTS)
PART NUMBER: --3072112--TFE731 ENGINE PART
NUMBER ON PLOT CORRESPONDS TO POSITION NUMBER
(I.E., 3 = TEST SAMPLE FROM POSITION 3 OF CASTING/FORGING



NOTE: 1) MISSING NUMBERS INDICATE DUPLICATION.
CHECK DATA (ACCORDING TO SERIAL NUMBER) FOR DUPLICATES.
2) AN ASTERISK (*) INDICATES A VALUE OUT OF LIMITS.

DETERMINATION OF A DIFFERENCE IN TESTING FOR
PART NUMBER: 3072112 LADISH PACIFIC TESTING VS. ARC CO. TESTING
DATA FROM 1/77 TO 5/79 (%REC.AREA)

SER.NO.	CERT DATA	CMR DATA	DIFFERENCE	DIFF.SQRD
2164	21.250	18.367	2.8830	8.3117
395	21.700	21.400	.3000	.0900
2392	19.775	16.467	3.3080	10.9429
92374	17.600	21.833	-4.2330	17.9183
93015	22.875	22.567	.3080	.0949
93345	12.600	24.100	-11.5000	132.2500
99800	18.500	25.700	-7.2000	51.8400
3040	21.775	23.133	-1.3580	1.8442
3046	24.950	23.700	1.2500	1.5625
3010	24.650	23.633	1.0170	1.0343
TOTAL			-15.2250	225.8857

AVERAGE DIFFERENCE = -1.5225 DEG. OF FREEDOM = 9

SAMPLE VARIANCE = 22.523 SAMPLE STANDARD DEV. = 4.75

THE "T." STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -1.0145
NULL HYPOTH.: $\mu 1-\mu 2$ = Dμ
ALT. HYPOTH.: $\mu 1-\mu 2$.NE.Dμ
ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

****ROOM TEMP.TENSILE TESTS-YIELD (AT.PAC.10/76 TO 5/79) CERT DATA
--3072310--TFE731 ENGINE PART
31 1 0 0 0
FORMAT(I5,F10.2)

SERIAL #			INPUT DATA BY POSITION
275	133.30	1209	142.60
230	125.90	1300	146.70
267	127.10	1301	143.40
223	135.40	960	135.30
152	130.10	909	141.00
155	129.90	949	141.00
4096	137.90	341	142.70
4069	139.30	2509	139.10
4025	143.80	2593	143.40
4014	140.70	1962	144.70
2607	137.50	1967	143.90
2609	139.90	1165	143.90
2575	136.30	390	132.40
2673	129.70	9919	159.60
1226	141.90	570	136.40
1202	137.90		

THE MEAN = 138.72 STAND DEV = 6.67
SUM = 4300.3[illegible] SUM OF SQUARES = 597869.42

1	133.30	125.90	127.10
2	135.40	130.10	129.90
3	137.90	139.30	143.80
4	140.70	137.50	139.90
5	136.30	129.70	141.90
6	137.90	142.60	146.70
7	143.40	135.30	141.00
8	141.00	142.70	139.10
9	143.40	144.70	143.90
10	143.90	132.40	159.60

**ROOM TEMP.TENSILE TESTS-YIELD LAC.PAC.(4/76 TO 5/79) CERT DATA

PART NUMBER: --3072316--TFE731 ENGINE PART

CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

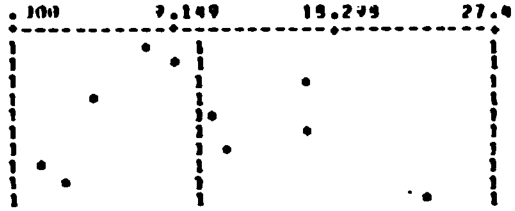
3 SIGMA-
RANGE CHART

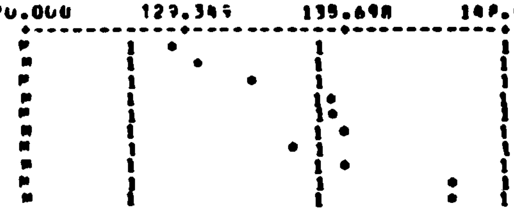
LCL= .0000
CENTER= 10.6900
UCL= 27.4476

3 SIGMA-
X-BAR CHART

LCL= 126.2537
CENTER= 137.1533
UCL= 148.0849

Range	Serial Number	X-bar
7.400	1	128.767
9.500	2	130.400
16.700	3	133.600
4.500	4	139.200
11.700	5	137.533
16.900	6	139.933
12.300	7	135.967
1.400	8	139.767
2.900	9	144.900
23.600	10	144.767





**ROOM TEMP.TENSILE TESTS-YIELD LAC.PAC.(4/76 TO 5/79) CERT DATA

PART NUMBER: --3072316--TFE731 ENGINE PART

CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

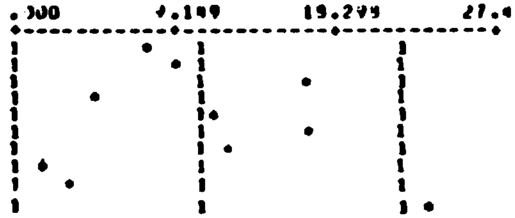
2 SIGMA-
RANGE CHART

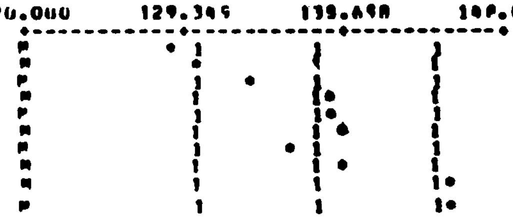
LCL= .0000
CENTER= 10.6900
UCL= 21.5232

2 SIGMA-
X-BAR CHART

LCL= 129.9909
CENTER= 137.1533
UCL= 144.4157

Range	Serial Number	X-bar
7.400	1	128.767
9.500	2	130.400
16.700	3	133.600
4.500	4	139.200
11.700	5	137.533
16.900	6	139.933
12.300	7	135.967
1.400	8	139.767
2.900	9	144.900
23.600	10	144.767





```
ROOM TEMP.TENSILE TESTS-YIELD LAT.PAC.(4/78 TO 9/80) CPR DATA
-3072316--TFE731 ENGINE PART
 27      1      0      0      0
FORMAT(I5,F10.2)
SERIAL #                      INPUT DATA BY POSITION

  267   135.20     2508   139.50
  223   136.30     2543   139.40
  152   133.60     1962   137.60
  155   137.60     1967   138.40
 2007   141.50     1165   146.20
 2609   145.20      380   137.50
 8575   148.30     8382   139.40
 2673   129.10     9819   129.73
 1226   148.50      570   150.70
 1202   136.30     2000   129.80
 1208   144.30     1950   136.50
                   THE MEAN =     139.73
  860   130.60
                   STAND DEV =       6.07
  909   145.60
                   SUM =   3765.90
  908   139.80
                   SUM OF SQUARES = 520823.80
 0711   128.10

  341   147.90
```

1	135.20	136.30	133.60
2	137.60	141.50	145.20
3	148.30	129.10	148.50
4	136.30	144.30	130.60
5	145.60	139.80	128.10
6	147.90	139.50	139.40
7	137.60	138.40	146.20
8	137.50	139.40	129.73
9	150.70	129.80	136.50

**ROOM TEMP.TENSILE TESTS-YIELD LAC.PAC.(4/76 TO 5/79) CMP DATA
PART NUMBER: --3072316--TFE731 ENGINE PART
CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

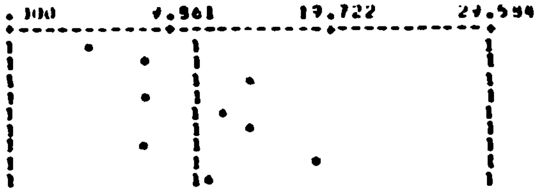
3 SIGMA-
RANGE CHART

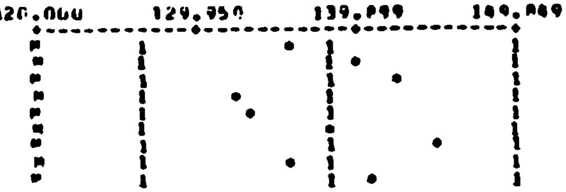
LCL= .0000
CENTER= 11.5111
UCL= 29.5936

3 SIGMA-
X-BAR CHART

LCL= 126.3661
CENTER= 139.1074
UCL= 149.8487

	SERIAL NUMBER	
4.700	1	135.700
9.200	2	140.167
14.900	3	142.433
7.900	4	132.033
13.400	5	133.300
15.200	6	137.967
8.500	7	144.767
19.900	8	135.567
12.000	9	141.133





**ROOM TEMP.TENSILE TESTS-YIELD LAC.PAC.(4/76 TO 5/79) CMP DATA
PART NUMBER: --3072316--TFE731 ENGINE PART
CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

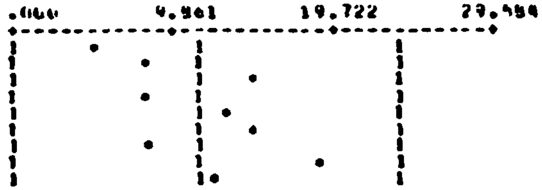
2 SIGMA-
RANGE CHART

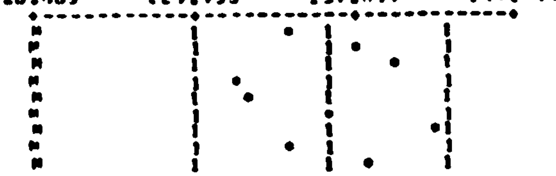
LCL= .0000
CENTER= 11.5111
UCL= 23.5215

2 SIGMA-
X-BAR CHART

LCL= 130.2799
CENTER= 139.1074
UCL= 145.9350

	SERIAL NUMBER	
4.700	1	135.700
9.200	2	140.167
14.900	3	142.433
7.900	4	132.133
13.400	5	133.300
15.200	6	137.967
9.500	7	144.767
19.800	8	135.567
12.000	9	141.133





252

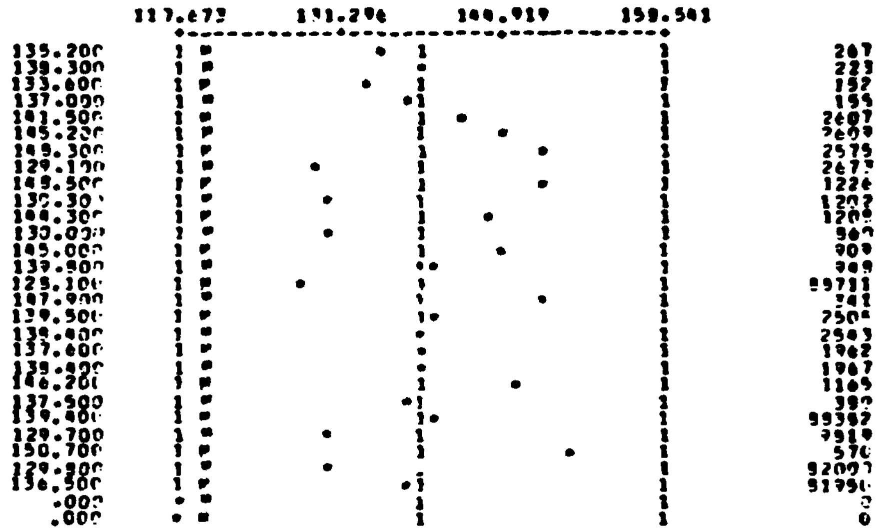
**ROOM TEMP.TENSILE TESTS-YIELD LOC.FAC.(4/76 TO 5/79) CERT DATA

PART NUMBER: --3372316--TFE731 ENGINE PART

INDIVIDUAL VALUE
X CHART

LCL= 117.6739
CENTER= 138.1076
UCL= 159.5413

SERIAL NUMBER



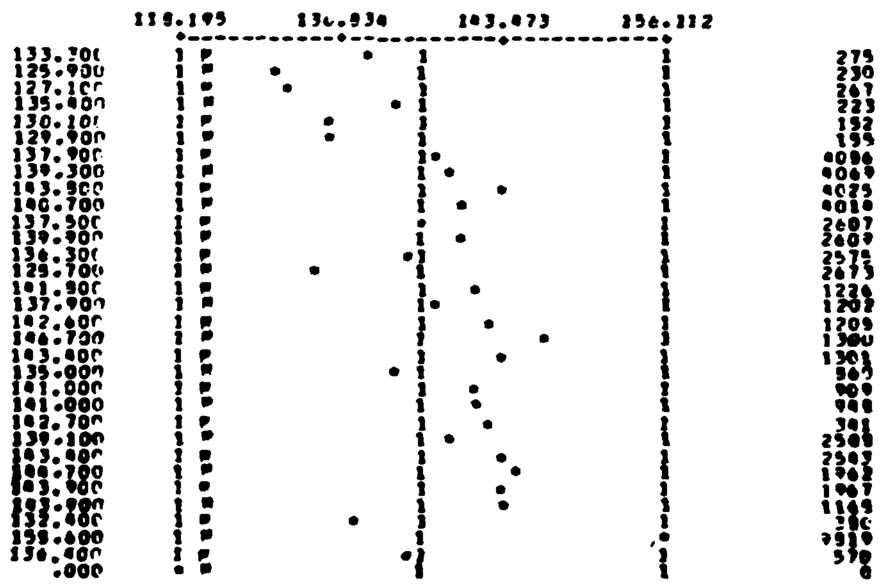
**ROOM TEMP.TENSILE TESTS-YIELD LOC.FAC.(4/76 TO 5/79) CERT DATA

PART NUMBER: --3372316--TFE731 ENGINE PART

INDIVIDUAL VALUE
X CHART

LCL= 118.1949
CENTER= 137.1533
UCL= 156.1115

SERIAL NUMBER



DETERMINATION OF A DIFFERENCE IN TESTING FOR
PART NUMBERS [illegible] PACIFIC TESTING VS. ARC CO. TESTING
DATA FROM 4/76 TO 5/79 (YIELD DATA)

SER.NO.	DEPT DATA	CMP DATA	DIFFERENCE	DIFF.SQRD
267	127.100	135.200	-8.1000	65.6100
223	136.400	139.300	-2.9000	8.4100
152	130.100	133.600	-3.5000	12.2500
155	129.900	137.000	-7.1000	50.4100
2667	137.500	141.500	-4.0000	16.0000
2639	139.900	145.200	-5.3000	28.0900
2575	136.300	148.300	-12.0000	144.0000
2673	129.700	129.100	-.4000	.1600
1276	141.900	148.500	-6.7000	44.8900
1202	137.900	130.300	7.6000	57.7600
1209	142.600	144.300	-1.7000	2.8900
962	135.000	130.000	5.0000	25.0000
909	141.000	145.000	-4.0000	16.0000
949	141.100	139.900	1.2000	1.4400
341	142.700	147.900	-5.2000	27.0400
2539	139.100	139.500	-.4000	.1600
2543	143.400	138.400	5.0000	25.0000
1962	144.700	137.600	7.1000	50.4100
1967	143.900	138.400	5.5000	30.2500
1165	143.900	146.200	-2.3000	5.2900
390	132.400	137.500	-5.1000	26.0100
9919	159.600	129.700	29.9000	935.2100
570	136.400	150.700	-14.3000	204.4900
TOTAL			-22.7000	1676.7700

AVERAGE DIFFERENCE = -.9870 DEG. OF FREEDOM = 22
SAMPLE VARIANCE = 75.194 SAMPLE STANDARD DEV. = 8.67

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -.5459
NULL HYPOTH.: U1-U2 = ZERO
ALT. HYPOTH.: U1-U2.NE.ZERO

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

```
*****ROOM TEMP.TENSILE TESTS-%ELONG. LAB.DOC.10/70 TO 9/78) CERT DATA
--3072316--TFE731 ENGINE PART
 30       1       0       0       0
FORMAT(I5,F10.2)
SERIAL #                    INPUT DATA BY POSITION

 275    22.00     1208    16.00
 230    20.00     1300    23.00
 267    19.00     1301    20.00
 223    22.00      860    23.00
 152    22.00      909    20.00
 155    22.00      948    24.00
0084    26.00      341    21.00
0069    22.00     2508    18.00
0025    22.00     2543    20.00
0014    27.00     1942    18.00
2007    22.00     1967    23.00
2609    20.00     1165    21.00
2575    19.00      390    22.00
2673    17.00     9919    20.00
1226    12.00      570    24.00
                  THE MEAN =     20.90  STAND DEV :     3.14
1207    15.00
                  SUM =    646.00  SUM OF SQUARES =  13759.00

   1    22.00    20.03    19.00
   2    23.00    22.00    22.00
   3    26.00    22.00    22.00
   4    27.00    22.00    20.00
   5    19.00    17.00    12.00
   6    15.00    16.03    23.00
   7    20.03    23.00    24.00
   8    24.00    21.03    18.00
   9    23.03    19.03    23.00
  10    21.00    22.00    20.00
```

**RDOM TEMP.TENSILE TESTS-%ELONG. LAC.PAC.(4/76 TO 5/79) CERT DATA

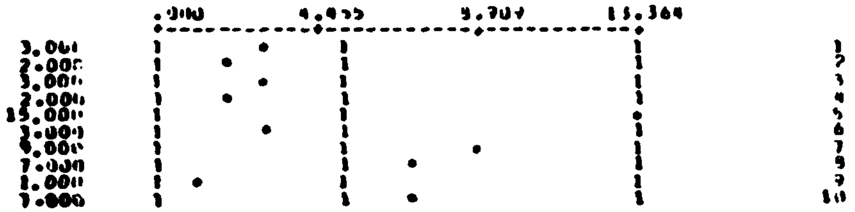
PART NUMBER: --3072316--TFE731 ENGINE PART

CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

3 SIGMA-
RANGE CHART

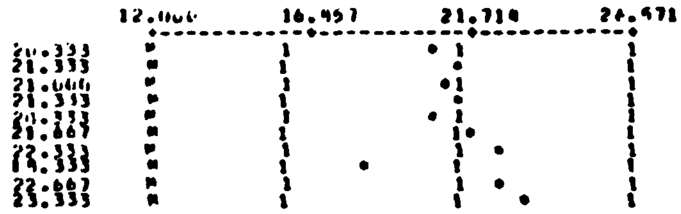
LCL= .0000
CENTER= 5.2000
UCL= 13.3643

SERIAL NUMBER



3 SIGMA-
X-BAR CHART

LCL= 15.9627
CENTER= 21.2667
UCL= 26.5707



**RDOM TEMP.TENSILE TESTS-%ELONG. LAC.PAC.(4/76 TO 5/79) CERT DATA

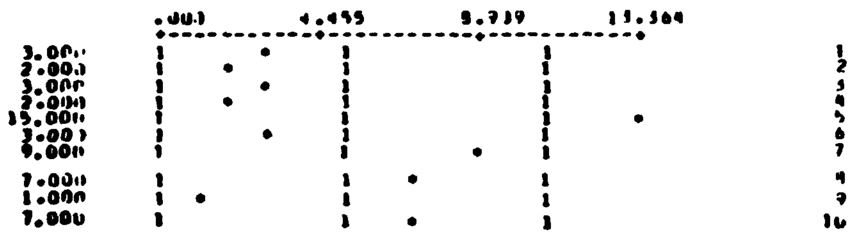
PART NUMBER: --3072316--TFE731 ENGINE PART

CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

2 SIGMA-
RANGE CHART

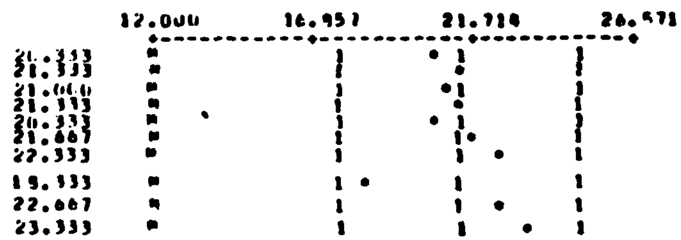
LCL= .0000
CENTER= 5.2000
UCL= 10.6255

SERIAL NUMBER



2 SIGMA-
X-BAR CHART

LCL= 17.7307
CENTER= 21.2667
UCL= 24.8027



***ROOM TEMP.TENSILE TESTS-%ELONG. LOC.PAC.(4/76 TO 5/78) COP DATA

--3072316--TFE731 ENGINE PART

27	1	0	0	0

FORMAT(I5,F10.2)

SERIAL # INPUT DATA BY POSITION

267	24.50	2509	26.30
223	22.50	2543	25.40
152	25.50	1962	24.00
155	25.00	1967	22.90
2607	28.00	1165	24.80
2609	26.40	390	24.70
2575	21.70	5392	21.40
2673	19.00	9919	29.50
1226	27.40	570	22.30
1202	25.30	2000	23.90
1209	25.00	1950	24.50
960	22.30		
909	24.50		
988	23.00		
0711	22.40		
341	23.00		

THE MEAN = 24.03

STAND DEV = 2.20

SUM = 648.90

SUM OF SQUARES = 15716.26

1	24.50	22.50	25.50
2	25.00	28.00	26.40
3	21.70	19.00	27.40
4	25.30	25.00	22.30
5	24.50	23.60	22.40
6	23.00	26.30	25.40
7	22.90	24.00	24.80
8	24.70	21.40	29.50
9	22.30	23.90	24.50

ROOM TEMP.TENSILE TESTS-%ELONG. LAC.PAC.(4/76 TO 5/78) PMP DATA

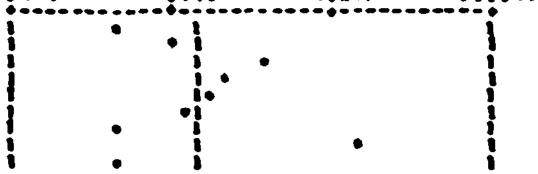
PART NUMBER: --3072316--TFE731 ENGINE PART

CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

3 SIGMA-
RANGE CHART

LCL= .0000 CENTER= 5.1999 UCL= 13.3354

.000 4.445 8.890 13.335



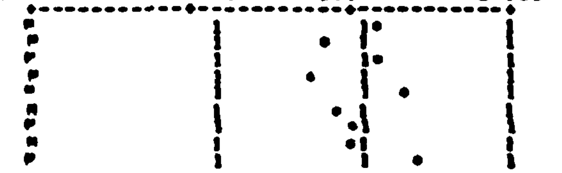
Range	Serial Number
3.000	1
4.400	2
7.000	3
6.000	4
5.600	5
5.000	6
3.100	7
9.500	8
2.900	9

3 SIGMA-
X-BAR CHART

LCL= 18.4740 CENTER= 23.7667 UCL= 29.0593

12.000 17.696 23.373 29.050

X-bar
24.167
22.633
24.433
22.100
25.233
22.700
23.367
23.500
25.767



ROOM TEMP.TENSILE TESTS-%ELONG. LAC.PAC.(4/76 TO 5/78) PMP DATA

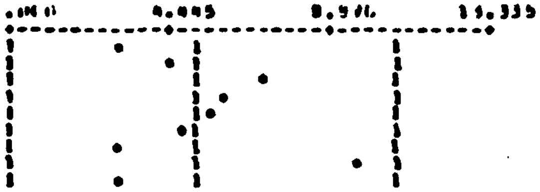
PART NUMBER: --3072316--TFE731 ENGINE PART

CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

2 SIGMA-
RANGE CHART

LCL= .0000 CENTER= 5.1999 UCL= 10.6024

.000 4.445 8.890 13.335



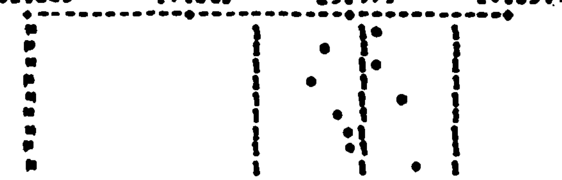
Range	Serial Number
3.000	1
4.400	2
7.000	3
6.000	4
5.600	5
5.000	6
3.100	7
9.500	8
2.900	9

2 SIGMA-
X-BAR CHART

LCL= 20.2382 CENTER= 23.7667 UCL= 27.2951

12.000 17.686 23.373 29.059

X-bar
24.167
22.633
24.433
22.100
25.233
22.700
23.367
23.500
25.767



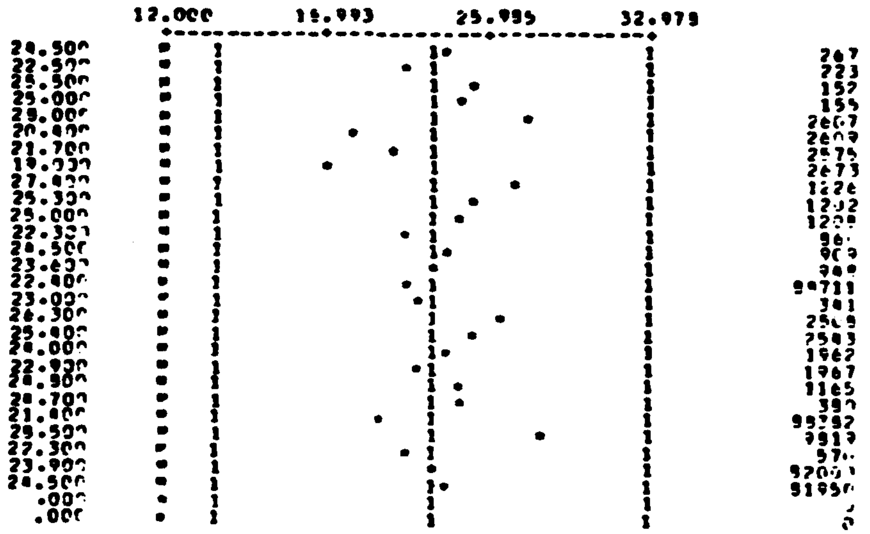
**ROOM TEMP.TENSILE TESTS-RELONG. LOC.PAC.(4/76 TO 5/78) FPR CATA

PART NUMBER: --3072316--TFE731 ENGINE PART

INDIVIDUAL VALUE
X CHART

LCL= 14.5556
CENTER= 23.7667
UCL= 32.9777

SERIAL NUMBER



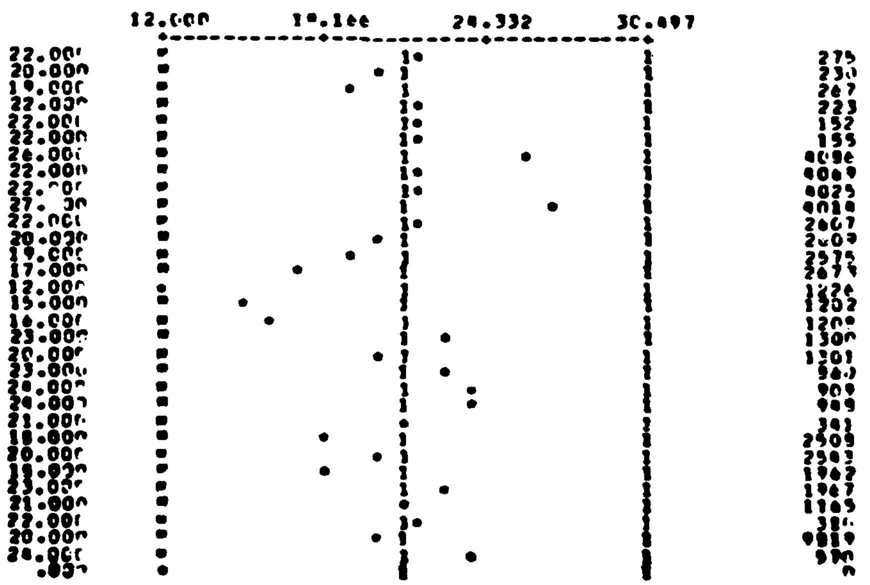
**ROOM TEMP.TENSILE TESTS-RELONG. LOC.PAC.(4/76 TO 5/78) CERT DATA

PART NUMBER: --3072316--TFE731 ENGINE PART

INDIVIDUAL VALUE
X CHART

LCL= 12.0359
CENTER= 21.2667
UCL= 30.4974

SERIAL NUMBER



DETERMINATION OF A DIFFERENCE IN TESTING FOR
PART NUMBER: 3072316 LACISH PACIFIC TESTING VS. APC CO. TESTING
DATA FROM 4/76 TO 5/79 (RELOKF. DATA)

SER.NO.	REPT DATA	CMP DATA	DIFFERENCE	DIFF.SQRD
267	19.000	24.500	-5.5000	30.2500
223	22.000	22.500	-.5000	.2500
152	22.000	25.500	-3.5000	12.2500
155	22.000	25.000	-3.0000	9.0000
2607	22.000	28.000	-6.0000	36.0000
2609	20.000	28.000	-8.0000	64.0000
2575	19.000	21.700	-2.7000	7.2900
2673	17.000	19.000	-2.0000	4.0000
1226	12.000	27.400	-15.4000	237.1600
1232	15.000	25.300	-10.3000	106.0900
1208	16.000	25.000	-9.0000	81.0000
960	23.000	22.300	.7000	.4900
909	24.000	24.500	-.5000	.2500
748	24.000	23.600	.4000	.1600
341	21.000	23.000	-2.0000	4.0000
2509	18.000	26.300	-8.3000	68.8900
2543	20.000	25.400	-5.4000	29.1600
1962	18.000	24.000	-6.0000	36.0000
1967	23.000	22.900	.1000	.0100
1165	21.000	24.800	-3.8000	14.4400
390	22.000	24.700	-2.7000	7.2900
9919	20.000	28.500	-8.5000	72.2500
570	24.000	22.300	1.7000	2.8900
TOTAL			-100.2000	823.1200

AVERAGE DIFFERENCE = -4.3565 DEG. OF FREEDOM = 22

SAMPLE VARIANCE = 17.573 SAMPLE STANDARD DEV. = 4.19

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -4.9801
NULL HYPOTH.: U1-U2 = ZERO
ALT. HYPOTH.: U1-U2.NE.ZERO

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

****ROOM TEMP TENSILE TESTS-SPEC.AREA LAE.PAC.(6/76 TO 5/79) CERT DATA

--3072316--TFE731 ENGINE PART

31 1 0 0 0

(FORMAT(I5,F10.2)

SERIAL # INPUT DATA BY POSITION

275	23.20	1208	36.00
230	25.30	1300	36.50
267	22.40	1301	26.10
223	26.10	860	27.30
152	23.20	909	31.30
155	27.90	949	29.70
4086	39.50	341	33.30
4069	32.30	2509	19.60
4025	30.10	2543	26.10
4014	34.50	1962	15.80
2607	26.70	1967	32.40
2609	21.60	1165	26.70
2575	22.40	390	29.20
2673	15.20	9919	26.40
1226	16.10	570	25.80
1202	15.20		

THE MEAN = 26.64 STAND DEV = 6.17

SUM = 825.71 SUM OF SQUARES = 23143.77

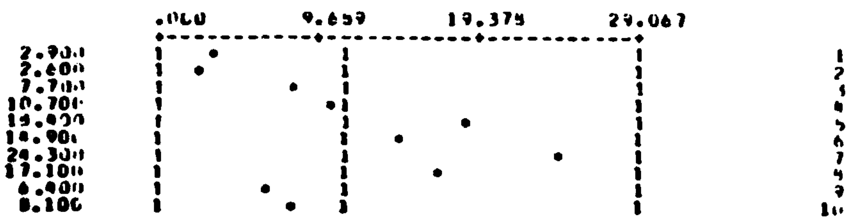
1	23.20	25.30	22.40
2	26.10	23.20	27.90
3	39.50	32.30	30.10
4	34.50	26.70	21.60
5	22.40	15.20	16.10
6	15.20	36.00	36.50
7	26.10	27.30	31.30
8	29.70	33.30	19.60
9	26.10	15.80	32.40
10	26.70	29.20	26.40

**ROOM TEMP TENSILE TESTS-SPEC.AREA LAC.PAC.(4/76 TO 5/79) CERT DATA
PART NUMBER: --3072316--TFE731 ENGINE PART
CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

3 SIGMA-
RANGE CHART

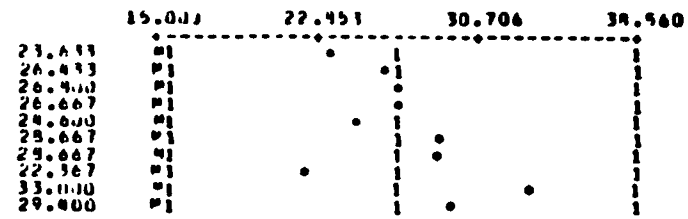
LCL= .0000
CENTER= 11.3100
UCL= 29.0667

SERIAL
NUMBER



3 SIGMA-
X-BAR CHART

LCL= 15.4971
CENTER= 27.0233
UCL= 38.5595

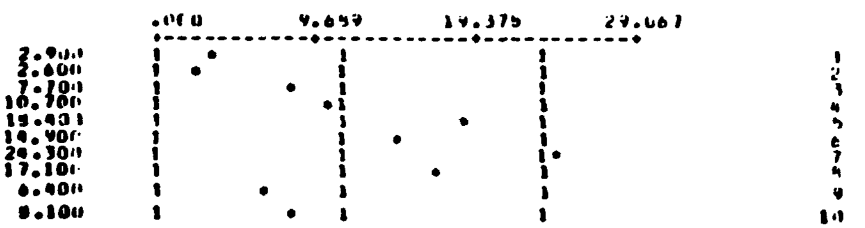


**ROOM TEMP TENSILE TESTS-SPEC.AREA LAC.PAC.(4/76 TO 5/79) CERT DATA
PART NUMBER: --3072316--TFE731 ENGINE PART
CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS

2 SIGMA-
RANGE CHART

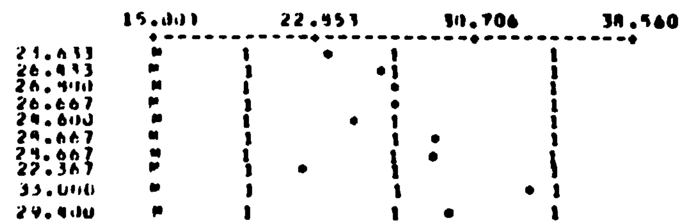
LCL= .0000
CENTER= 11.3100
UCL= 23.1105

SERIAL
NUMBER



2 SIGMA-
X-BAR CHART

LCL= 19.3325
CENTER= 27.0233
UCL= 34.7141



***ROOM TEMP.TENSILE TESTS-PREF.AREA LAT.PAR.(6/76 TO 5/7?)
--3072316--TFE731 ENGINE PART CMC DATA

27 1 0 0 0

FORMAT(I5,F10.2)

SERIAL # INPUT DATA BY POSITION

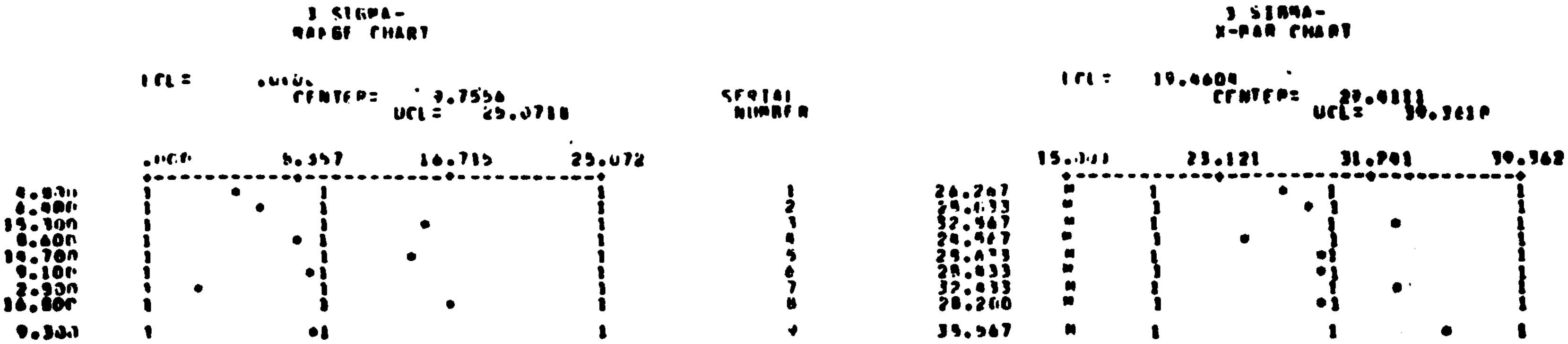
267	28.50	2508	29.40
223	24.00	2543	32.00
152	26.00	1962	29.50
155	29.70	1967	30.70
2607	37.30	1165	34.20
2609	30.40	350	36.00
2575	31.40	0392	25.30
2673	21.10	9919	37.90
1226	41.30	570	25.40
1202	26.00	2000	31.10
1208	39.20	1950	33.40
860	22.90	THE MEAN =	30.24
909	33.50	STAND DEV =	5.31
948	31.70	SUM =	816.40
0721	22.60	SUM OF SQUARES =	25417.32
341	25.60		

1	24.50	24.00	26.00
2	29.70	37.30	30.40
3	31.40	21.10	41.10
4	26.00	39.20	22.90
5	33.50	31.70	22.60
6	25.60	29.40	32.00
7	29.50	30.70	34.20
8	36.00	25.30	37.90
9	25.40	31.10	33.40

**ROOM TEMP.TENSILE TESTS-SPEC.AREA LAC.PAC.(4/76 TO 5/78) CMR DATA

PART NUMBER: --3072316--TFE731 ENGINE PART

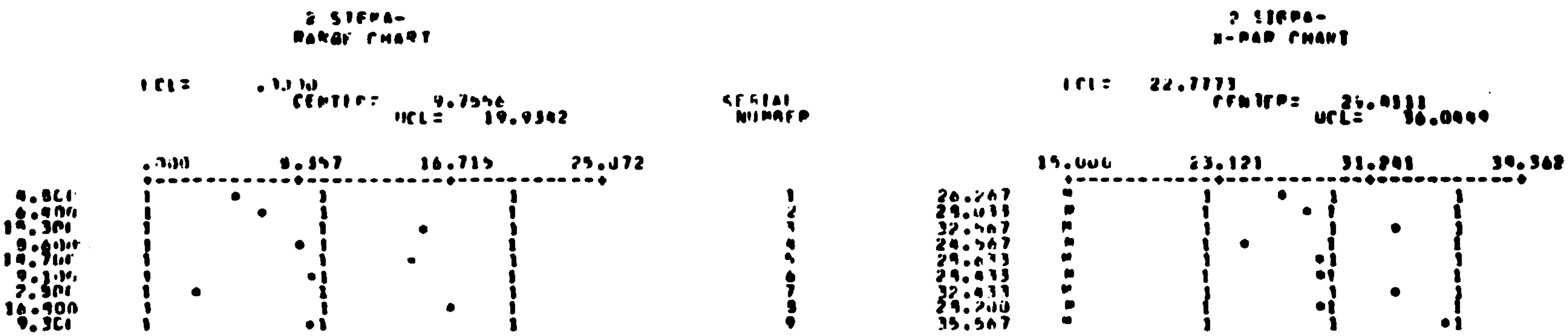
CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS



ROOM TEMP.TENSILE TESTS-SPEC.AREA LAC.PAC.(4/76 TO 5/78) CMR DATA

PART NUMBER: --3072316--TFE731 ENGINE PART

CHARTS FOR GROUPS OF 3 CASTINGS/FORGINGS



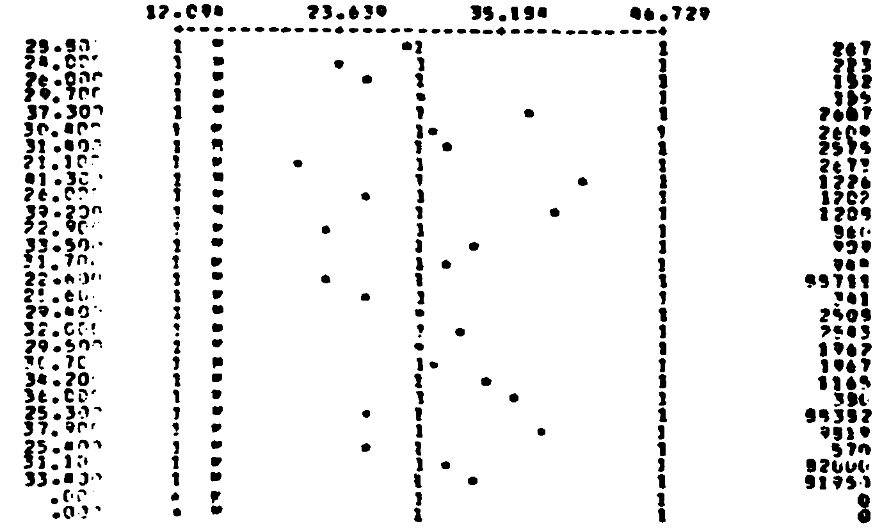
ROOM TEMP. TENSILE TESTS-RED. AREA LOC.PAC.(4/76 TO 5/79) CERT DATA

PART NUMBER: --3072316--TFE731 ENGINE PART

INDIVIDUAL VALUE
X CHART

LCL= 12.3336
CENTER= 29.5131
UCL= 46.7297

SERIAL NUMBER



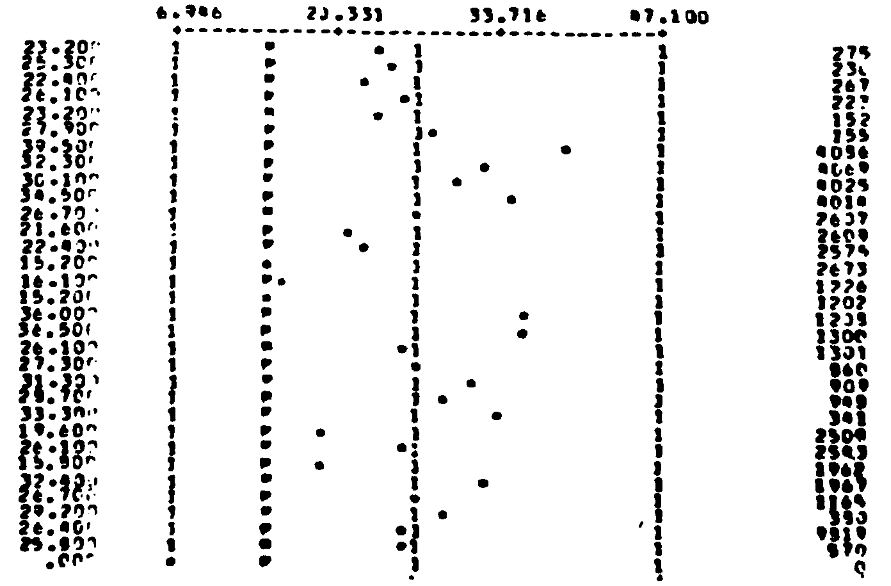
ROOM TEMP TENSILE TESTS-RED.AREA LOC.PAC.(4/76 TO 5/79) CERT DATA

PART NUMBER: --3072316--TFE731 ENGINE PART

INDIVIDUAL VALUE
X CHART

LCL= 6.9464
CENTER= 27.0233
UCL= 47.1003

SERIAL NUMBER



DETERMINATION OF A DIFFERENCE IN TESTING FOR
PART NUMBER: SOUTHERN LOCISH PACIFIC TESTING VS. MFR CO. TESTING
DATA FROM 4/76 TO 5/79 (SPEC. AREA)

SER.NO.	CERT DATA	MFR DATA	DIFFERENCE	DIFF.SQRD
267	22.400	29.900	-6.4000	40.9600
223	26.100	24.000	2.1000	4.4100
157	23.200	26.000	-2.8000	7.8400
155	27.400	29.700	-1.8000	3.2400
2607	26.700	37.300	-10.6000	112.3600
2639	21.600	30.400	-8.8000	77.4400
2575	22.400	31.400	-9.0000	81.0000
2673	15.200	21.100	-5.9000	34.8100
1226	16.100	41.300	-25.2000	635.0400
1202	15.200	26.000	-10.8000	116.6400
1206	36.000	39.200	-3.2000	10.2400
960	27.300	22.900	4.4000	19.3600
969	31.300	33.500	-2.2000	4.8400
948	29.700	31.700	-3.0000	9.0000
343	33.300	25.600	7.7000	59.2900
2539	19.600	29.400	-9.8000	96.0400
2543	26.100	32.000	-5.9000	34.8100
1962	18.800	29.500	-10.7000	114.4900
1967	32.400	30.700	1.7000	2.8900
1165	26.700	34.200	-7.5000	56.2500
390	29.200	36.000	-6.8000	46.2400
9919	26.400	37.900	-11.5000	132.2500
576	25.800	25.400	.4000	.1600
TOTAL			-125.6000	1679.5999

DIFFERENCE = -5.4609 DEG. OF FREEDOM = 22

SAMPLE VARIANCE = 46.774 SAMPLE STANDARD DEV. = 6.79

THE "T" STATISTIC FOR TESTING THE DIFFERENCE IN THE TWO TESTING MEANS = -3.8592
NULL HYPOTH.: U1-U2 = ZERO
ALT. HYPOTH.: U1-U2.NE.ZERO

ASSUMPTION: THE DISTRIBUTION UNDERLYING THE DIFFERENCES IS NORMAL.

APPENDIX F

Given: The following data concerning test results (tensile yield) from four different positions on a Waspalloy forging Part No. 3072112.

PART#	POSITION # 3	4	5	7	x_i	x_i^2
1	132.2	133.8	132.8	133.2	532	70757.36
2	132.7	137.8	135.1	134.3	539.9	72886.63
3	135.9	137.	132.7	133.7	539.3	72722.79
4	137.6	139.6	140.7	138.1	556	77290.02
5	137.2	136.4	135.5	136.8	545.9	74503.29
6	139.5	138.3	142 2	138.7	558.7	78045.67
7	135.6	135.2	130.8	136.5	538.1	72407.29
8	138.9	138.5	137.5	139.5	554.4	76841.96
9	136.4	134.0	135.9	135.9	542.2	73498.58
10	133.3	131.1	131.3	135.7	531.4	70610.28
11	132,3	131.6	131.2	136.3	531.4	70612.98
12	144.3	142.7	141.5	140.2	568.7	80864.07
TOT	1635.9	1636.0	1627.2	1638.9	6538.0	
TOT^2	223152.99	223166.64	220833.80	223887.49		891040.92

Find: The results of analysis of variance including:

1) Equality of variances for the twelve items (Cochran's Test)
2) A one-way analysis to look @ equality of means of the different positions
3) A two-way analysis to look @ equality of means of both positions and parts.

SOLUTION:

1) $$s_1^2 = \frac{12(223152.99)-(1635.9)^2}{12(11)} = 12.629$$

2) $$s_2^2 = \frac{12(223166.64)-(1636.0)^2}{(132)} = 11.392$$

3) $$s_3^2 = \frac{12(220833.80)-(1627.2)^2}{(132)} = 16.862$$

4) $$s_4^2 = \frac{12(223887.49)-(1638.9)^2}{(132)} = 4.97$$

SOLUTION(cont'd):

$$g = \frac{\text{Largest } S_i^2}{\text{Total } S^2} = \frac{16.862}{45.853} = .3677$$

significant @ =.01
n=4,k=12

2)

$$SST = \text{Sum } x_i^2 - \frac{(\text{sum } x_i)^2}{n}$$

$$= 891040.92 - \frac{(6538)^2}{48} = 510.8367$$

$$SS_{trt} = \frac{(1635.9)^2+(1627.2)^2+(1638.9)^2+(1636)^2}{12} - \frac{(6538)^2}{48} = 6.405$$

$$SS_E = 510.8367 - 6.405 = 504.432$$

SOURCE	D.F.	SS_x	MS_x	F	
Position	3	6.405	2.135	.1862	not signif.
Error	44	504.432	11.464		
Total	47	510,837			

3)

$$SS_{bl} = ((532)^2+(539.9)^2+(539.3)^2+(556)^2+(545.9)^2+ (558.7)^2+(538.1)^2+554.4)^2+(542.2)^2+2(531.4)^2 +(568.7)^2)/4 - \frac{(6538)^2}{48}$$

$$= 403.03$$

$$SS_E = 510.837 - (403.03 + 6.405) = 101.410$$

SOURCE	D.F.	SS_x	MS_x	F	
Position	3	6.405	2.135	.6948	sig @ lt.01
Item	11	403.03	36.639	11.9229	reject H_o
Error	33	101.410	3.073		
Total	47	510.837			

Duncan's Test on 3072112 CMR Data - Yield

Data Table:

Position	3	4	5
	133.9	134.7	135.4
	134.4	135.0	139.4
	138.9	138.3	138.9
	135.6	140.6	134.1
	130.43	134.8	132.4
	133.0	135.3	132.7
	133.6	134.4	134.6
	133.3	136.6	132.4
	139.1	138.7	135.7
	133.4	135.4	132.4
	134.4	134.4	130.3
	132.6	135.8	131.2
	132.2	132.2	132.6
	139.2	138.9	136.5
Total	1884.03	1905.10	1868.60
Average	134.57	136.08	133.47

MSE = 6.375 $\qquad S_{\bar{x}} = \left(\frac{6.375}{14}\right)^{1/2} = 0.675$

Test this Position

Pos 5	Pos 3	Pos 4
133.47	134.57	136.08

@ α=.05 $\quad$ p $\quad$ 2 $\quad$ 3

d.f.=39 $\quad r_p$ = 2.86 $\quad$ 3.01

$R_p = S_{\bar{x}} \cdot r_p \quad R_p$ = 1.93 $\quad$ 2.03

@ p=3 $\quad 136.08 - 133.47 = 2.61 \nless 2.03$

@ p=2 (3:4) $\quad 136.08 - 134.57 = 1.51$
(5:3) $\quad 134.57 - 133.47 = 1.01$ } both < 1.93

@ α=.01 $\quad$ 133.47 $\quad$ 134.57 $\quad$ 136.08

d.f.=39 $\quad$ p $\quad$ 2 $\quad$ 3

r_p = 3.82 $\quad$ 3.99

R_p = 2.58 $\quad$ 2.69 $\qquad$ None signif.

Duncan's Test on 3072112 CERT Data - Yield

Data Table: (see data of analysis of variance above)

Position	3	4	5	7
Total	1635.9	1636.0	1627.2	1638.9
Average	136.32	136.33	135.6	136.57

MSE = 11.465 $\quad S_{\bar{x}} = \left(\frac{11.465}{12}\right)^{1/2} = 0.977$

Pos 5	Pos 3	Pos 4	Pos 7
135.6	136.32	136.33	136.57

@ α=.05	p	2	3	4
	r_p =	2.85	3.00	3.09
	R_p =	2.78	2.93	3.02

@ p=4 $\quad 136.57 - 135.6 = 0.97 < 3.02$

No further testing necessary.

Conclusion: None are any less significant than any other mean value.

BIOGRAPHICAL SKETCH

Daniel E. Gellenbeck was born in Canton, Ohio on March 12, 1951. He received his elementary education in parochial schools in Canton and Charlotte, North Carolina and in the Phoenix, Arizona, public school system, where he also received his secondary education.

In 1969, he entered Arizona State University, graduating in 1973 with a Bachelor of Science in Mechanical Engineering and receiving a commission in the U. S. Air Force as a Second Lieutenant through the A. F. Reserve Officer Training Corps program.

November 1973 saw him enter active duty and undergraduate pilot training at Laughlin AFB, Texas. After receiving his pilot's wings in December 1974, he was assigned to Altus AFB, Oklahoma, remaining there until June, 1978 when he was assigned to Arizona State University for work on the Master of Science degree in Industrial Engineering. While there, he was inducted into the Alpha Pi Mu Honorary Society.

Reassigned to Myrtle Beach AFB, South Carolina, in September 1979, he was stationed at Myrtle Beach AFB to November 1981; Thule AB, Greenland November 1981 to November 1982, and Tinker AFB, Oklahoma November 1982 to present. Major Gellenbeck is presently serving as an Airborne Warning and Control System (AWACS) Aircraft Commander at Tinker, deploying frequently to locations around the world. He is a senior pilot and has received the Air Medal, two Air Force Commendation Medals, the Outstanding Unit Award, and several lesser commendations.

Major Gellenbeck and his wife, Debbie, have three daughters: Dawn Joann, Danna Marie, and Darla Ann.

END
DTIC
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